TECHNICAL REPORT ADDENDUM

Edible Oil Barriers for Treatment of Perchlorate Contaminated Groundwater

ESTCP Project ER-0221

MARCH 2008

Solutions – IES, Inc.

Environmental Security Technology Certification Program

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Edible Oil Barriers for Treatment of Perchlorate Contaminated Groundwater

Technical Report Addendum

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Solutions-IES
Industrial & Environmental Services

March 2008

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

LIST OF ABBREVIATIONS USED IN THIS DOCUMENT

1. AP – Ammonium Perchlorate
2. CAH – Chlorinated Aliphatic Hydrocarbons
3. Cl# - Chlorine Number
4. 1,1-DCA – 1,1-Dichloroethane
5. 1,2-DCA – 1,2-Dichloroethane
6. *cis*-DCE – *cis*-1,2-Dichloroethene
7. *trans*-DCE – *trans*-1,2-Dichloroethene
8. DNAPL – Dense Non-Aqueous Phase Liquid
9. DO – Dissolved Oxygen
10. DoD – Department of Defense
11. DOC – Dissolved Organic Carbon
12. EISOPQAM – Environmental Investigation Standard Operating Procedure and Quality Assurance Manual
13. EOS® - Edible Oil Substrate; Emulsified Oil Substrate
14. ESTCP – Environmental Security Technology Certification Program
15. ITRC – Interstate Technology & Regulatory Council
16. O&M – Operation and Maintenance
17. ORP – Oxidation-Reduction Potential
18. PCE – Tetrachloroethene (Tetrachloroethylene)
19. PRB – Permeable Reactive Barrier
20. 1,1,1-TCA – 1,1,1-Trichloroethane
21. TCE – Trichloroethene (Trichloroethylene)
22. TIC – Total Inorganic Carbon
23. TOC – Total Organic Carbon
24. US EPA – United States Environmental Protection Agency
25. VC – Vinyl Chloride
26. VOC – Volatile Organic Compound

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EXECUTIVE SUMMARY

This *Technical Report Addendum* documents longevity and continued effectiveness of emulsified edible oil substrate for remediation of perchlorate and chlorinated solvents in groundwater. The project was funded by the Environmental Security Technology Certification Program (ESTCP; ER-0221). The substrate used for the demonstration was EOS®, a commercially available concentrated edible (soybean) oil/nutrient emulsion purchased from EOS Remediation, Inc. of Raleigh, NC. The demonstration was conducted at the Alliant Techsystems, Inc. site (ATK) in Elkton, MD. The field demonstration began in October 2003 with the initial performance monitoring period ending in April 2005. Because good results were observed, ESTCP funded an additional two years of monitoring to further evaluate the technology.

The longevity and extended performance of the technology were evaluated by monitoring the impact of the emulsified oil on the aquifer permeability and continued changes in contaminant concentrations and biodegradation indicator parameters in the aquifer. Data obtained during the pilot test were used to demonstrate the cost-effectiveness of emulsified edible oils for remediation of perchlorate, chlorinated ethanes and ethenes in groundwater through enhanced biodegradation.

Demonstration Design

The groundwater was characterized by a mixed perchlorate, 1,1,1-trichloroethane (1,1,1-TCA), tetrachloroethene (PCE) and trichloroethene (TCE) contaminant plume. The water table is approximately 5 ft bgs. The groundwater velocity in the pilot test area during the demonstration period varied from 140 to almost 1000 ft/year due to changes in the operation of a groundwater extraction system.

The field demonstration consisted of a one-time injection of EOS® and chase water to create a 50-ft long permeable reactive barrier (PRB). In October 2003, approximately 110 gallons of EOS® and 2,070 gallons of water were injected into the subsurface. Monitoring activities were originally conducted over an 18-month period to evaluate performance of the PRB. Additional monitoring was conducted over the subsequent 24-month period, ending in April 2007 to evaluate the longevity of the substrate.

Summary of Results

EOS® injection resulted in increased levels of organic carbon in groundwater, resulting in anaerobic conditions and enhanced anaerobic biodegradation of perchlorate, 1,1,1-TCA, PCE and TCE. Total organic carbon (TOC) levels in groundwater increased immediately after EOS® injection, and remained elevated for two years. However, by 2.6 years after injection, TOC levels in the injection wells dropped below 5 mg/L suggesting that much of the bioavailable organic carbon had been depleted. Results from a mass balance analysis indicate that 65% of the injected organic carbon had been consumed prior to the decline in TOC indicating relatively efficient use of the injected substrate. At 42 months after EOS® injection, 76% of the injected carbon had been consumed.

Geochemical data collected at the site confirmed that anaerobic conditions favorable for biodegradation of these compounds were quickly established in the treatment area. In general, nitrate and sulfate concentrations decreased in the injection and downgradient wells indicating nitrate and sulfate reduction, while iron (Fe^{+2}) and manganese (Mn^{+2}) concentrations increased indicating iron and manganese reducing conditions. Methane concentrations increased indicating methanogenic conditions within the PRB. No significant changes were observed in the upgradient monitor wells.

The single injection of 110 gallons (840 lbs) of EOS® effectively created a 50-ft long PRB to intercept contaminated groundwater across a 10-ft vertical interval of the aquifer. The substrate was very effective in stimulating perchlorate biodegradation. Perchlorate concentrations in all of the injection wells were reduced to below detection (<4 µg/L) within 5 days of EOS® injection. Maximum efficiencies were observed during both the first 4 months and during a period between year 2 and 3 when groundwater flow velocity slowed (due to shutdown of a nearby downgradient groundwater recovery and treatment system) and contact time in the PRB increased. At the end of the extended monitoring period (after 3.5 years), residual TOC was limited and the resumption of pump and treat system operation resulted in a drop in perchlorate removal efficiency. However, in the groundwater 20 feet downgradient of the PRB, the perchlorate concentrations remained one to two orders of magnitude less than the concentrations entering the PRB over the entire 42-month period. Over this 3.5 year period, 76% of the injected substrate had been consumed indicating very efficient substrate utilization.

The emulsified oil substrate PRB was also effective in enhancing reductive dechlorination. 1,1,1-TCA, PCE and TCE were biodegraded during transport through the biobarrier as demonstrated by increases in the concentration of daughter products (1,2-DCA, CA, *cis*-1,2-DCE, VC and ethene) and declines in chlorine number. Dechlorination efficiency reached a maximum between year 2 and 3, when groundwater flow velocity slowed and contact time in the PRB increased due to shut down of a downgradient extraction trench. During the first two years when dechlorination was most efficient, 65% of the injected substrate was consumed.

Based on data collected during the original 18-month pilot test, the effective longevity of the EOS® barrier was estimated to be approximately 2 to 2.5 years. Long term monitoring showed the barrier was effective in treating both perchlorate and chlorinated solvents for 2.5 to 3.5 years. The average hydraulic conductivity downgradient of the biobarrier was typically higher than both the upgradient and injection wells. In general, hydraulic conductivity was not adversely affected by the introduction of emulsified oil. Increased contact time in the PRB was shown to be desirable for both utilizing residual organic substrate and achieving regulatory cleanup goals.

1.0 Introduction

The original work on this ESTCP-funded project began in April 2002 (ER-0221). As part of that project, a field demonstration using emulsified edible oil to stimulate biodegradation of perchlorate started in September 2003. A final technical report titled "*Edible Oil Barriers for Treatment of Perchlorate Contaminated Groundwater*" (*Technical Report;* Solutions-IES, 2006*)* documented the results of the 18-month pilot test that was conducted. The finalized report was submitted in February 2006. However, prior to completion of the demonstration, ESTCP funded an additional two years of monitoring to evaluate the longevity and long-term effectiveness of the technology. This addendum to the technical report (*Technical Report Addendum*) documents the findings from the extended monitoring activities.

1.1 Background

The background regarding the use of perchlorate and its place as a major environmental issue for the US Department of Defense (DoD) was discussed in the *Technical Report* (Solutions-IES, 2006). A comprehensive review of the issues, status and remedial options pertaining to perchlorate in the environment can be found in the ITRC Technology Overview (ITRC, 2005). In general, man-made perchlorate can enter groundwater through the release and/or disposal of ammonium perchlorate (AP), a strong oxidant that is used extensively in solid rocket fuel, munitions, and pyrotechnics. Perchlorate is highly soluble in water and poorly sorbs to mineral surfaces.

Chlorinated solvents in groundwater are also a frequently encountered problem at DoD facilities. In recent years, anaerobic reductive dechlorination has been shown to be an efficient microbial means of transforming more highly chlorinated species to less chlorinated species. Chlorinated solvents amenable to *in situ* anaerobic bioremediation, and the reactions by which they degrade, can be found in the *Technical Report* (Solutions-IES, 2006) as well as other DoD and EPA-sponsored documents such as *Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents* (AFCEE, 2004) and *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* (USEPA, 1998).

This project was conducted in Area C at the Alliant Techsystems, Inc. (ATK) facility in Elkton, MD. The project was designed to test and evaluate an innovative, cost-effective approach for distributing and immobilizing biodegradable organic substrates in contaminated aquifers to promote biodegradation of perchlorate and chlorinated solvents in groundwater. The initial work involved the one-time injection of low solubility, slowly biodegradable, edible oil-in-water emulsion to provide the primary source of organic carbon to promote and sustain long-term anaerobic biodegradation of target contaminants. The emulsified oil substrate (EOS® obtained from EOS Remediation, Inc., Raleigh, NC) was distributed via a linear array of ten injection wells forming a permeable reactive barrier (PRB). This provided good contact between the oil and the contaminants and resulted in excellent removal of contaminants passing through the PRB. The introduction of EOS® into the subsurface successfully stimulated the biodegradation of perchlorate, 1,1,1-trichloroethane (1,1,1-TCA), tetrachloroethene (PCE) and trichloroethene (TCE) in groundwater.

1.2 Objectives of the Demonstration and Regulatory Drivers

The objective of the original demonstration project was to evaluate the cost and performance of an edible oil emulsion PRB for stimulating biodegradation of perchlorate and controlling the migration of perchlorate plumes. Because of the presence of chlorinated ethane and chlorinated ethene compounds as co-contaminants in the groundwater, the effectiveness of emulsified oil substrate for promoting the degradation of these solvents was also evaluated. Based on the success achieved in the initial study as documented in the *Technical Report* (Solutions-IES, 2006), extended monitoring of the demonstration was authorized to evaluate the longevity and long-term effectiveness of the edible oil emulsion PRB.

The regulatory drivers for groundwater remediation were discussed in the *Technical Report* (Solutions-IES, 2006). In January 2006, the USEPA issued “Assessment Guidance for Perchlorate” identifying 24.5 µg/L as the recommended value “to be considered” (TBC) and preliminary remediation goal for perchlorate (USEPA, 2006). The State of Maryland has not yet promulgated a perchlorate standard for groundwater but issued a “health advisory level” of 1 µg/L in 2002.

Chlorinated solvents in groundwater are regulated on a federal level by the National Primary Drinking Water Regulations, which establish maximum contaminant levels (MCLs) for drinking water to protect human health. The Maryland Department of the Environment (MDE) Generic Numeric Cleanup Standards for Groundwater for the primary constituents at the Maryland project site are summarized in **Table 2-1.** Although not a primary performance monitoring criterion of this project, the effectiveness of the EOS® technology to achieve the current regulatory standards was also evaluated.

Table 2-1
Maryland Department of the Environment
Generic Numeric Cleanup Standards for Groundwater (Update No. 1, August 2001)
Type I and II Aquifers

Compound	Concentration (µg/L)
Tetrachloroethene (PCE)	5
Trichloroethene (TCE)	5
cis-1,2-Dichloroethene (*cis*-DCE)	70
trans-1,2-Dichloroethene (*trans*-DCE)	100
Vinyl chloride	2
1,1,1-Trichloroethane (TCA)	200
1,1-Dichloroethane (1,1-DCA)	80
1,2-Dichloroethane (1,2-DCA)	5
1,1-Dichloroethene (1,1-DCE)	7
Chloroethane (CA)	3.6
Chloroform	100
Bromoform	100
Perchlorate	No Standard

2.0 Technology Description

2.1 Technology Development and Application

The emulsified oil process is a cost-effective approach for delivering a low solubility, slowly degradable, long-lasting substrate to the subsurface to enhance the anaerobic biodegradation of perchlorate and chlorinated solvents. The process by which the addition of substrate enhances *in situ* biodegradation of perchlorate and chlorinated ethanes and ethenes is similar, although the microbial populations and metabolic pathways differ. .

In both cases, emulsified oil substrate introduced into the contaminated aquifer is first gradually fermented over time by indigenous microflora, providing a slow continuous source of dissolved organic carbon (DOC) and hydrogen (H_2) to support anaerobic biodegradation of the target contaminants. The initial fermentation reaction is illustrated in equation 1:

(1) $C_{56}H_{100}O_6$ (**oil**) + 106 H_2O – ***Fermenting Bacteria*** → 56 CO_2 + 156 H_2

Coates and Achenbach (2006) state that "…perchlorate-reducing microorganisms exhibit a broad range of metabolic capabilities including the oxidation of hydrogen, simple organic acids and alcohols, aromatic hydrocarbons, hexoses, reduced humic substances , both soluble and insoluble ferrous iron and hydrogen sulfide," but are not "known to utilize complex substrates such as methyl soyate, molasses, or various edible oils…" More than 50 dissimilatory perchlorate-reducing bacteria have been cultured (Coates and Achenbach, 2006). The substrate enhanced, enzyme-mediated metabolism of perchlorate proceeds by the sequential removal of chloride atoms from the anion as shown in equation 2.

(2)	ClO_4^-	→	ClO_3^-	→	ClO_2^-	→	Cl^- + O_2
	Perchlorate		Chlorate		Chlorite		Chloride + Oxygen

Far fewer microbial species can biodegrade 1,1,1-TCA, PCE and TCE and dehalorespiring microorganisms are generally more fastidious about their substrate and environmental conditions. The degradation of 1,1,1-TCA is carried out principally by <u>Dehalobacter spp.</u> (ESTCP, 2005; Grostern and Edwards, 2006); PCE and TCE can be biodegraded to *cis*-DCE by many classifications and strains of dechlorinating bacteria found in the subsurface environment, but only <u>Dehalococcoides ethenogenes</u> is capable of complete degradation of PCE, TCE or *cis*-DCE to ethene (AFCEE, 2004). The initial microbially-mediated conversion step of 1,1,1-TCA and TCE is a sequential reduction of the chlorinated molecule requiring the presence of H^+ as shown in equations 3a and 3b.

(3a) $C_2H_3Cl_3$ (**1,1,1-TCA**) + H_2 – ***Dehalorespiring Bacteria*** → $C_2H_3Cl_2$ (**1,1-DCA**) + Cl^- + H^+

(3b) C_2HCl_3 (**TCE**) + H_2 - ***Dehalorespiring Bacteria*** →$C_2H_2Cl_2$ (***cis/trans*-1,2-DCE**) + Cl^-+H^+

Using conventional wells or direct-push injection points, emulsified oil can be injected into "hot spots" as a source area treatment, throughout a contaminant plume, or as a permeable reactive barrier to intercept contaminant flow. The amount of emulsified oil injected into the subsurface is determined based on the concentrations of the target compounds, the concentrations of various

biogeochemical parameters, the amount of competing electron acceptors, and the geologic and hydrogeologic conditions.

2.2 Factors Affecting Cost and Performance

The primary costs associated with installation of emulsified oil substrate barriers include injection point installation, substrate used, and labor for substrate injection. These costs are affected by the mass of contaminants in the aquifer, the subsurface lithology, the depth to groundwater, and the vertical extent of contamination. The performance of an emulsified oil PRB for remediating perchlorate and chlorinated solvents is primarily related to the ability to distribute the substrate throughout the treatment zone, the biodegradability of the substrate after it is injected, the presence of microorganisms capable of complete biodegradation of the target contaminants, and the rate of biodegradation of the target contaminants that can be achieved *in situ*. More detailed descriptions of these contributing factors, as well as advantages and limitations of the technology, can be found in the *Technical Report* (Solutions-IES, 2006).

Secondary costs associated with the technology include the longevity of the substrate in the aquifer. Factors controlling these costs include the amount of substrate introduced into the aquifer during the initial injection phase, the groundwater hydrology, and losses due to non-specific biodegradation and consumption of substrate to satisfy the donor demand. The long-term performance of the PRB installed for the original demonstration at the ATK site in Elkton, MD is the subject of this *Technical Report Addendum*.

3.0 Demonstration Design

The original demonstration involved installing a pilot-scale EOS® PRB and monitoring the PRB performance over an 18-month period. The extended demonstration involved additional monitoring of the PRB over a subsequent 24-month period. Data obtained during the entire 42-month pilot test were used to evaluate the longevity and extended effectiveness of the approach. During the initial 18 months, the performance of the PRB was evaluated by monitoring the distribution of the EOS® in the subsurface, changes in contaminant mass, changes in groundwater biogeochemistry and the impact of the emulsion injection on aquifer permeability and groundwater flow. During the subsequent 24-month extended monitoring period, performance continued to focus on changes to contaminant mass, as well as groundwater biogeochemistry and long-term impact on aquifer permeability.

3.1 Experimental Design

The results of the site characterization activities, laboratory microcosm studies, and laboratory column tests were used to aid in the design of the EOS® PRB. Detailed explanations of the following design components can be found in the *Technical Report* (Solutions-IES, 2006):

- Screen interval of the injection wells;
- Spacing of the injections wells;
- Amount of substrate; and
- Total injection volume (substrate and chase water).

Two drums of EOS® concentrate (110 gallons; 840 lbs) and 2,090 gallons of water were injected to create the PRB (**Figure 3-1**). A limited amount of substrate was used in this demonstration so that oil depletion/reduced treatment efficiency could be observed within the 18-month timeframe of the project. However, at the end of 18 months, the PRB was still functioning adequately, so the monitoring period was extended for an additional 24 months to monitor the oil depletion and loss of efficiency as originally planned.

3.2 Sampling Plan

Sampling activities conducted during the 24-month extended monitoring period focused exclusively on groundwater sampling to monitor the EOS® performance and aquifer testing to evaluate permeability effects. The sampling activities were conducted in accordance with the Quality Assurance Project Plan, which was provided in the Technology Demonstration Plan (Solutions-IES, 2003). The analytical/testing methods that were used are identified in Section 3.3. Brief explanations of plan development, data collection methods and sampling procedures are included below. More detailed descriptions of the sampling operations employed during the demonstration can be found in the *Technical Report* (Solutions-IES, 2006).

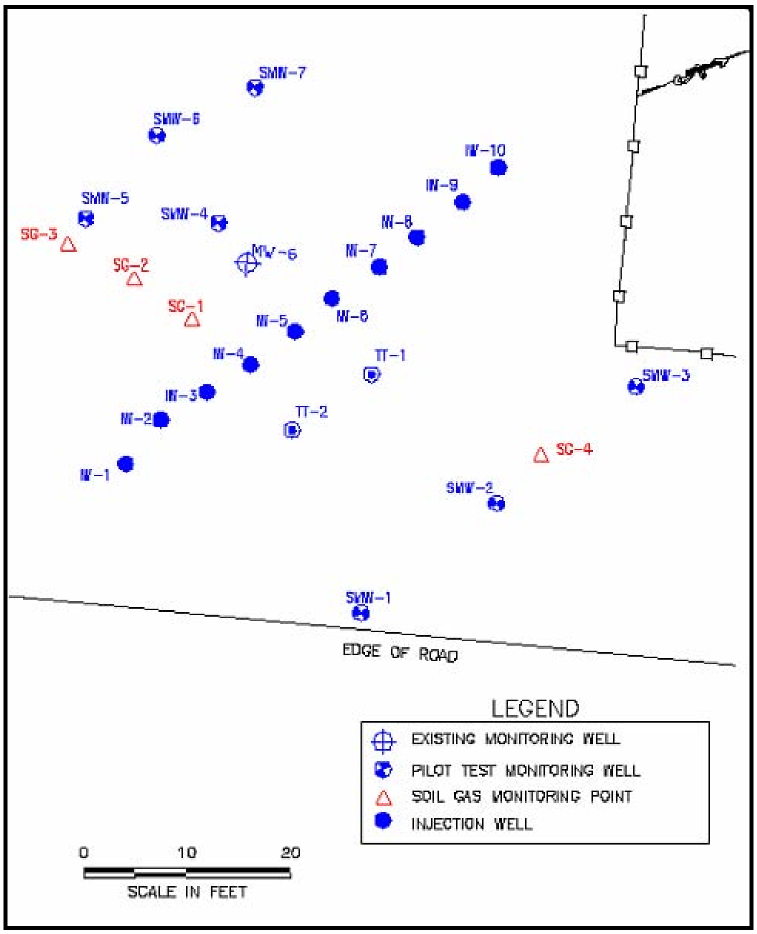

Figure 3.1 Pilot Test Layout

3.2.1 Groundwater Sampling

Baseline groundwater sampling was conducted as part of the site characterization activities prior to injection. Performance monitoring was initiated after the oil emulsion was injected to form the PRB and included the collection of samples 4 days after injection and then on Day 35 (~1 mo.), Day 68 (~2 mo.), Day 133 (~4 mo.), Day 348 (~11 mo.), Day 560 (~18 mo.), Day 741 (~24 mo.), Day 900 (~30 mo.), Day 1126 (~36 mo.) and Day 1272 (~42 mo.).

In general, purging and sampling protocols followed the procedures outlined in *Environmental Investigations Standard Operating Procedures and Quality Assurance Manual* (EISOPQAM; EPA, 1997). Prior to the collection of groundwater samples, water level measurements were collected for each well using a water level interface probe. Each well to be sampled was then purged until the pH, specific conductance, and temperature of the groundwater had stabilized. The wells were sampled using a peristaltic pump and low-flow purging and sampling methods.

Field measurements were then recorded and groundwater samples were collected for analysis. Laboratory sample containers were immediately sealed, labeled, and placed on ice for delivery to the analytical laboratory. Chain-of-custody forms accompanied all samples sent to the laboratory. The sequence of sample collection for analysis is detailed in the *Technical Report* (Solutions-IES, 2006).

3.2.2 Permeability Testing

Hydraulic conductivity testing was performed before and after injection to evaluate permeability changes. As mentioned in Section 4.3.5, slug-in and slug-out tests or specific capacity tests were performed on selected injection and monitor wells during the demonstration project. Pre-injection testing was conducted on April 14 and 23, 2003 and June 24, 2003. Post-injection testing was conducted 4, 18, and 42 months after creating the PRB.

3.2.3 Demobilization

At the request of the site owner, pilot test injection wells and monitor wells were left in place for potential future use.

3.3 Selection of Analytical/Testing Methods

Analytical methods and laboratories used during this demonstration are listed in **Table 3-1**. For continuity, the laboratories where the analyses were conducted during the initial performance monitoring, as reported in the *Technical Report*, were maintained during the extended monitoring period.

Table 3-1
Analytical Methods and Laboratories

Analyte	Analytical Method	Laboratory
Perchlorate	EPA Method 314.0	Babcock Labs Riverside, CA
Chlorinated Aliphatic Hydrocarbons (CAHs)	EPA Method 6230 (GC, only)	Prism Laboratories Charlotte, NC
Methane, Ethane, Ethene	Gas chromatography	VaporTech Valencia, PA
Chloride, Sulfate	Ion Chromatography	NCSU Env. Eng. Lab*, Raleigh, NC
Nitrate, Nitrite	Ion Chromatography	NCSU Env. Eng. Lab, Raleigh, NC
Phosphate	Ion Chromatography	NCSU Env. Eng. Lab, Raleigh, NC
Total Organic Carbon, Total Inorganic Carbon	EPA Method 415.1	Prism Laboratories Charlotte, NC
Volatile Fatty Acids	Modified EPA Method 8015	Microbial Insights Rockford, TN
Manganese, Arsenic	EPA Method 3010A (sample prep) EPA Method 6010B (analysis)	Prism Laboratories Charlotte, NC
Dissolved Iron	Filtration and EPA Method 3010A (sample prep) EPA Method 6010B (analysis)	Prism Laboratories Charlotte, NC

* NCSU = North Carolina State University

4.0 Performance Assessment

The following subsections discuss the data obtained during the entire pilot study but primarily discuss the 24-month extended monitoring period focusing on the two primary objectives of the demonstration: 1) evaluating the longevity of the emulsified oil in the subsurface and 2) the long-term effectiveness of the PRB. The discussion of data obtained during the original 18-month demonstration project can be found in the *Technical Report* (Solutions-IES, 2006). Complete data sets for individual wells from the inception to the completion of the project are provided in **Appendix A**.

4.1 Groundwater Hydraulics

The site characteristics were described in Section 3 of the *Technical Report.* The pilot test barrier was constructed in an open grassy area approximately 150 feet downgradient from the presumed source of the contamination. A pump-and-treat system is currently used to treat impacted groundwater in this area. Groundwater is extracted from an interceptor trench, treated via an air stripper, and re-injected via an upgradient infiltration gallery. The groundwater interceptor trench is located approximately 50 feet downgradient of the PRB.

At each sampling event, groundwater elevations were recorded in monitoring and injection wells across the pilot study area. The results are summarized in **Table 4-1**. The gradient through the PRB ranged between 0.005 and 0.014 ft/ft during the period before injection through the sampling conducted on April 20, 2005 (Day 559) post-injection. As discussed later in this report (see Section 4.2.4.4) and in the *Technical Report*, increases in dissolved iron and manganese were observed in the pilot test area. Along with residual BOD released from the PRB, these changes in metals concentrations were implicated in floc formation in the interceptor trench and fouling of the air stripper. Consequently, the air stripper and groundwater extraction system were shut down by the site operators beginning in May 2005. During the following 16 months when the groundwater extraction trench was not operating, the hydraulic gradient dropped to between 0.002 and 0.004 ft/ft. The air stripper was restarted in September 2006. The gradient measured during the November 2006 (Day 1127) still reflected the shutdown period, but by April 2007 (Day 1272) the gradient had increased to 0.011 ft/ft, similar to the pre-shutdown conditions.

Table 4-1 also provides calculations of groundwater flow velocities. Using a hydraulic conductivity of 35 ft/day and effective porosity of 0.18, flow velocities ranged from 0.9 to 2.7 ft/day before the groundwater pump-and-treat system was shut down and dropped to 0.4 to 0.8 ft/day when the downgradient groundwater recovery stopped.

Table 4-1
Groundwater Elevation Data, Groundwater Flow Velocity and Residence Time through the Permeable Reactive Barrier.

		Groundwater Elevation (ft amsl)									
	Location from Barrier (feet)	**7/24/2003**	**9/29/2003**	**11/12/2003**	**12/15/2003**	**2/17/2004**	**4/20/2005**	**10/19/2005**	**3/27/2006**	**11/9/2006**	**4/3/2007**
Well ID	**Days from Injection**	**-77**	**-10**	**34**	**67**	**131**	**559**	**741**	**900**	**1127**	**1272**
SMW-1	-25	33.23	37.09	36.57	37.42	36.84	35.30	34.07	34.71	37.77	35.68
SMW-2	-25	33.80	37.14	36.54	37.43	36.78	35.32	34.04	34.68	37.73	35.67
SMW-3	-25	33.58	36.80	36.31	37.19	36.54	35.09	33.80	34.46	37.10	35.48
IW-1	0	33.38	36.89	36.11	37.12	36.63	35.01	34.60	34.58	37.57	35.40
IW-2	0	33.45	36.92	36.00	37.23	36.75	35.13	34.09	34.69	37.64	35.47
IW-3	0	33.36	36.71	35.94	36.96	36.50	34.89	33.88	34.45	37.38	35.24
IW-4	0	33.73	36.98	36.25	37.25	36.79	35.09	34.19	34.72	37.67	35.54
IW-5	0	33.59	36.81	36.10	37.11	36.63	35.05	34.06	34.56	37.51	35.38
IW-6	0	33.48	36.66	36.00	37.02	36.53	34.97	33.91	34.47	37.44	35.29
IW-7	0	33.62	36.75	36.25	37.23	36.66	35.16	34.04	34.66	37.62	35.50
IW-8	0	33.70	36.91	36.40	37.30	36.81	35.31	34.13	34.74	37.71	35.59
IW-9	0	33.40	36.69	36.09	37.01	36.52	34.97	33.80	34.44	37.39	35.30
IW-10	0	33.62	36.87	36.30	37.24	36.73	35.19	34.01	34.65	37.62	35.54
MW-6	7.5	33.49	36.82	36.08	36.68	36.59	34.98	33.96	34.55	36.99	35.29
SMW-4	12.5	33.41	36.79	35.99	37.00	36.58	34.95	33.93	34.53	37.41	35.24
SMW-5	20	33.36	36.77	35.93	36.94	36.55	34.94	33.95	34.53	37.41	35.20
SMW-6	20	33.15	36.59	35.75	36.76	36.46	34.77	33.81	34.38	37.31	35.02
SMW-7	20	33.28	36.70	35.88	36.84	36.48	34.88	33.88	34.46	37.31	35.15
	Hydraulic Gradient	0.006	0.007	0.014	0.011	0.005	0.008	0.002	0.004	0.004	0.011
	GW flow velocity (ft/d)*	1.18	1.40	2.68	2.16	0.97	1.61	0.39	0.69	0.82	2.10
	GW flow velocity (ft/y)*	431	510	978	789	352	589	142	252	300	768
	Residence Time in Treatment Zone (days)										
	10 ft	8.5	7.2	3.7	4.6	10.4	6.2	25.7	14.5	12.2	4.8

*Calculations based on average hydraulic conductivity (K) = 35 ft/d and effective porosity = 0.18
Downgradient recovery trench and air stripping system shut down on May 15, 2005 (Day 584) and restarted on September 8, 2006 (Day 1064).

4.2 Longevity of the Oil Emulsion

The total organic carbon (TOC) in groundwater was used to measure organic carbon that was added to the aquifer and is readily available for microbial metabolism. Total inorganic carbon (TIC) in groundwater was measured to serve as an indicator of microbial activity. TIC concentration is the sum of carbon dioxide, carbonate and bicarbonate. By measuring TIC before and after addition of substrate, the difference can serve as an indicator of active degradative processes.

The longevity of the oil emulsion substrate was evaluated by assessing the presence of residual TOC in the injection wells and downgradient monitor wells. The average TOC concentrations throughout the entire 42-month demonstration period are summarized in **Table 4-2.** The extended monitoring period comprises samples collected from Day 741 (~24 months) through Day 1272 (~42 months). Results shown are the calculated average concentrations of TOC and total inorganic carbon (TIC) in the three wells upgradient of the PRB (SMW-1, SMW-2, and SMW-3), five of 10 injection wells that comprise the PRB (IW-1, IW-3, IW-5, IW-7 and IW-10) and three monitor wells approximately 20-ft downgradient of the PRB (SMW-5, SMW-6 and SMW-7). The data from each well are shown in **Appendix A, Table A-1**.

Table 4-2
Total Organic and Inorganic Carbon in Groundwater

Well ID (Distance from Barrier)	Sample Date	Days (Months) Since Injection		Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Methane (mg/L)	Total TOC, TIC & Methane (mg/L)
UPGRADIENT MONITORING WELLS							
Average of 3 Monitor Wells 25 feet Upgradient of Biobarrier	9/30/03	-9		0.82	23.2	0.001	24.0
	10/13/03	4	(~0.1)	2.29	20.5	0.002	22.8
	11/13/03	35	(~1)	1.73	18.6	0.001	20.4
	12/16/03	68	(~2)	<1.0	21.3	0.001	21.8
	2/19/04	133	(~4)	0.37	17.9	0.001	18.3
	9/21/04	348	(~11)	0.39	19.7	0.003	20.1
	4/21/05	560	(~18)	0.90	23.4	0.004	24.3
	10/19/05	741	(~24)	1.01	22.6	0.009	23.7
	3/27/06	900	(~30)	1.00	12.3	0.000	13.3
	11/8/06	1126	(~36)	0.33	19.1	0.003	19.5
	4/3/07	1272	(~42)	1.01	23.5	0.004	24.5
INJECTION WELLS							
Average of 5 Injection Wells in Biobarrier	9/29/03	-10		0.7	23.0	0.000	23.7
	10/13/03	4	(~0.1)	259.2	43.4	0.001	302.6
	11/13/03	35	(~1)	52.9	40.9	0.008	93.8
	12/16/03	68	(~2)	57.2	40.5	0.099	97.8
	2/19/04	133	(~4)	39.2	28.0	0.361	67.6
	9/21/04	348	(~11)	40.3	28.9	3.398	72.6
	4/21/05	560	(~18)	20.5	29.9	3.028	53.4
	10/20/05	742	(~24)	34.7	58.2	5.789	98.7
	3/28/06	901	(~30)	3.8	21.9	4.498	30.2
	11/8/06	1126	(~36)	2.4	28.2	4.006	34.6
	4/3/07	1272	(~42)	2.0	27.2	2.436	31.6
DOWNGRADIENT MONITORING WELLS							
Average of 3 Monitor Wells 20 feet Downgradient of Biobarrier	9/30/03	-9		<1.0	22.6	0.000	23.1
	10/14/03	5	(~0.1)	24.5	25.1	0.000	49.6
	11/13/03	35	(~1)	14.1	54.1	0.001	68.2
	12/16/03	68	(~2)	5.47	29.7	0.001	35.1
	2/18/04	132	(~4)	7.78	27.3	0.205	35.3
	9/22/04	349	(~11)	38.5	24.4	3.873	66.8
	4/21/05	560	(~18)	16.7	27.4	2.890	47.0
	10/20/05	742	(~24)	6.46	55.0	5.752	67.2
	3/28/06	901	(~30)	1.70	10.2	5.324	17.2
	11/8/06	1126	(~36)	1.61	19.2	1.212	22.1
	4/3/07	1272	(~42)	2.10	24.6	3.585	30.3

The impact of the injection on the TOC in groundwater is clearly shown by the large jump to an average of 259 mg/L in the five injection wells four days after injection of the emulsified oil substrate. An increase in the monitor wells 20 feet downgradient of the barrier was also noted, but the magnitude (24.5 mg/L) was not as great. This initial downgradient response to the injection of EOS® is likely attributable to transport of the more soluble components in the substrate, most notably lactic acid, away from the injection points during the creation of the PRB.

The average TIC concentrations in the injection wells and downgradient also increased soon after the addition of substrate. Over 54 mg/L TIC were reported in the downgradient monitor wells after two years. Beyond 2 years, TIC concentrations returned to pre-injection or unamended levels.

As shown in **Table 4-2** and **Figure 4-1**, the TOC slowly decreased over time both in the injection wells and downgradient of the barrier, but the average concentration of TOC in the area between the injection points and the monitor wells 20 feet downgradient was approximately 20 mg/L even 742 days (approximately 2 years) post-injection. When sampled at 900 days (2.4 years), the average TOC in the injection wells had declined to 3.8 mg/L suggesting that much of the bioavailable organic carbon had been depleted. However, inorganic carbon in the injection wells remained higher than in upgradient wells indicating that some substrate was still available to generate anaerobic conditions.

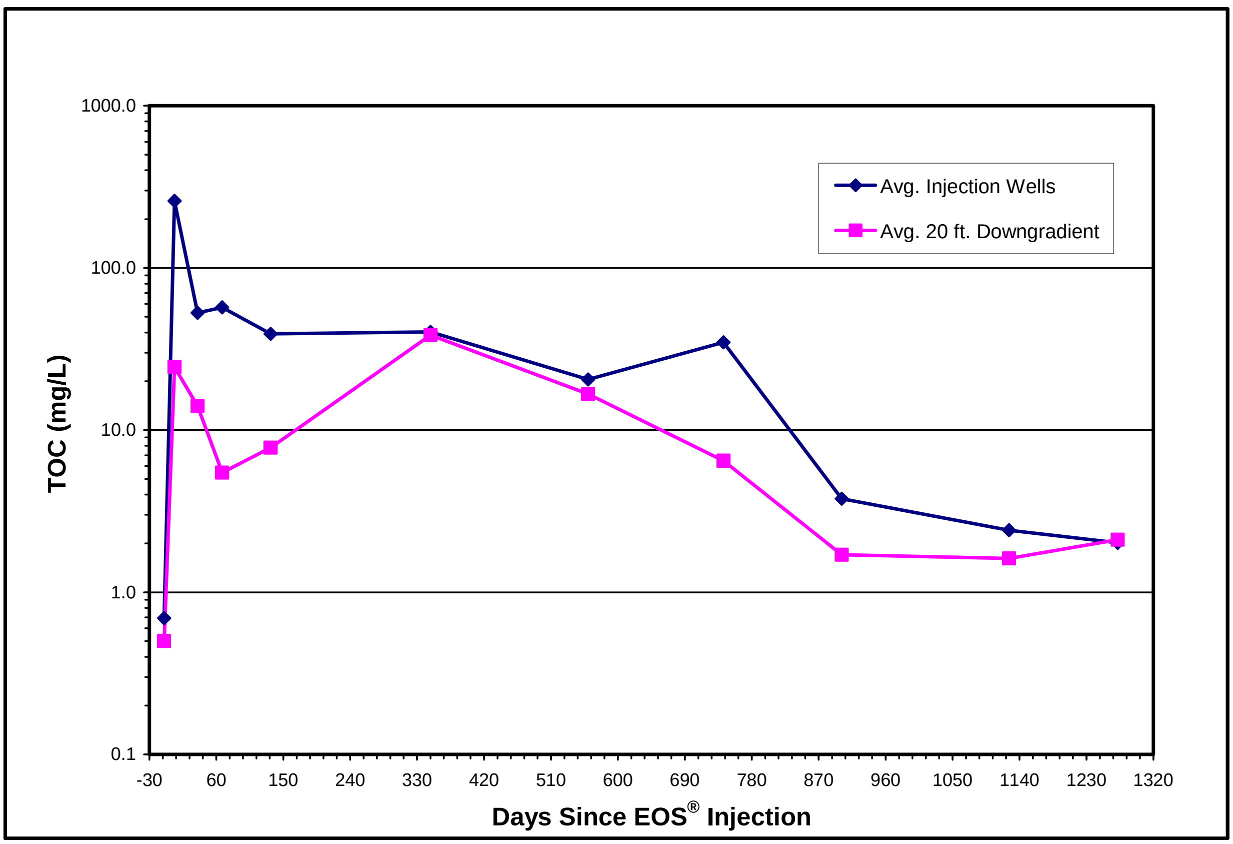

Figure 4-1. TOC Trends during the 3.5-year Monitoring Period after EOS® Injection

The longevity of the barrier was originally estimated by developing a mass balance of organic and inorganic carbon entering and discharging from the barrier and calculating the oil demand based on observed changes in contaminants and biogeochemical parameters. Changes in TIC and TOC during passage through the barrier were determined by comparing the average TIC and TOC concentrations in wells upgradient and within the barrier. Carbon from methane was also added, since this carbon was likely missed by the TOC analysis due to the volatility of methane. **Table 4-3** shows the carbon calculations which indicate that on average 67 mg/L of carbon was released from the barrier during the 42-month monitoring period. A time-weighted average was also calculated as 37 mg/L of carbon released by the barrier. The time-weighted average is probably more representative due to the high initial release of carbon which skews the average. Assuming a 50-ft wide by 10-ft deep barrier with an average groundwater flow velocity of 400 ft/yr and porosity of 18%, the barrier released an average of 0.23 pounds of carbon per day (time-weighted average).

Table 4-3
Carbon Released by Biobarrier

Sample Date	Days (Months) Since Injection		Average 25 ft Upgradient (mg/L)	Average Injection Wells (mg/L)	Carbon Released by Barrier (mg/L)
9/30/03	-9		24.0	23.7	
10/13/03	4	(~0.1)	22.8	302.6	279.8
11/13/03	35	(~1)	20.4	93.8	73.4
12/16/03	68	(~2)	21.8	97.8	76.0
2/19/04	133	(~4)	18.3	67.6	49.3
9/21/04	348	(~11)	20.1	72.6	52.5
4/21/05	560	(~18)	24.3	53.4	29.1
10/19/05	741	(~24)	23.7	98.7	75.0
3/27/06	900	(~30)	13.3	30.2	16.9
11/8/06	1126	(~36)	19.5	34.6	15.1
4/3/07	1272	(~42)	24.5	31.6	7.1
Average over 42 months (mg/L)					**67**
Time-weighted average over 42 months (mg/L)					**37**

The mass flux of carbon discharging from the barrier was then compared with the amount of carbon injected to develop an approximate substrate life. Accounting for only the carbon from the soybean oil in the EOS®, approximately 380 pounds of carbon were injected (assuming EOS® is 60% soybean oil, and soybean oil is 75% carbon). Over the first 2.6 years when the barrier was releasing significant amounts of TOC, approximately 244 lb or 65% of the injected carbon was released. Over the entire 42-month monitoring period 289 lb or 76% of the injected carbon was released.

The substrate life was also estimated using observed changes in contaminant concentrations and biogeochemical parameters. The average difference between the three upgradient wells and three wells 20 feet downgradient over the course of the 18-month pilot test was determined. These values were then entered into the oil demand spreadsheet (*Technical Report*, Appendix D). Using these data, the spreadsheet calculated a substrate life of 2.7 years based on injection of 110 gallons (840 lbs) of EOS® concentrate. Based on the results of the pilot test, this prediction was reasonably close to the observed TOC concentrations.

4.3 Long-term Effectiveness of the EOS® PRB

The long-term remediation effectiveness of the PRB was evaluated by assessing the duration that the residual EOS® continued to promote degradation of perchlorate and enhance reductive dechlorination of the chlorinated ethanes and ethenes. Changes in biogeochemical parameters were also evaluated. The following sections discuss the overall 42-month demonstration with focus on the final 24-month extended monitoring period.

4.3.1 Perchlorate

The EOS® PRB continued to be effective at degrading perchlorate throughout the 24-month extended demonstration period. The perchlorate data are summarized in **Table 4-4** and presented graphically in **Figure 4-2**. Data from individual wells are provided in tables in **Appendix A, Table A-2.**

Table 4-4
Summary of Perchlorate in Groundwater

Well ID (Distance from barrier)	Sample Date	Days (Months) Since Injection		Perchlorate (μg/L)	Perchlorate (μM)	Perchlorate % Reduction
UPGRADIENT MONITORING WELLS						
Average of 3 Monitor Wells 25 ft Upgradient of Biobarrier	9/30/03	-9		8,833	88.9	NA
	10/14/03	4	(~0.1)	32,800	330.0	NA
	11/13/03	35	(~1)	8,900	89.5	NA
	12/16/03	68	(~2)	8,733	87.9	NA
	2/19/04	133	(~4)	7,367	74.1	NA
	9/21/04	348	(~11)	11,233	113.0	NA
	4/21/05	560	(~18)	5,400	54.3	NA
	10/19/05	741	(~24)	13,100	131.8	NA
	3/27/06	900	(~30)	6,000	60.4	NA
	11/10/06	1126	(~36)	5,880	59.2	NA
	4/3/07	1272	(~42)	4,333	43.6	NA
INJECTION WELLS						
Average of 5 Injection Wells In Biobarrier	9/29/03	-9		9,680	97.4	-10%
	10/14/03	4	(~0.1)	<4	<0.04	100.0%
	11/13/03	35	(~1)	<4	<0.04	100.0%
	12/16/03	68	(~2)	89	0.9	99.0%
	2/18/04	133	(~4)	473	4.8	93.6%
	9/21/04	348	(~11)	1,356	13.6	87.9%
	4/21/05	560	(~18)	984	9.9	81.8%
	10/20/05	741	(~24)	190	1.9	98.5%
	3/28/06	900	(~30)	996	10.0	83.4%
	11/10/06	1126	(~36)	1,045	10.5	82.2%
	4/3/07	1272	(~42)	1,327	13.4	69.4%
DOWNGRADIENT MONITORING WELLS						
Average of 3 Monitor Wells 20 ft Downgradient of Biobarrier	9/30/03	-9		8,667	87	2%
	10/14/03	4	(~0.1)	4,567	46	86.1%
	11/13/03	35	(~1)	8	0.1	99.9%
	12/16/03	68	(~2)	63	0.6	99.3%
	2/18/04	133	(~4)	31	0.3	99.6%
	9/22/04	348	(~11)	151	1.5	98.7%
	4/21/05	560	(~18)	15	0.1	99.7%
	10/20/05	741	(~24)	2.7	0.03	100.0%
	3/28/06	900	(~30)	11	0.11	99.8%
	11/10/06	1126	(~36)	103	1.04	98.2%
	4/3/07	1272	(~42)	128	1.28	97.1%

a. Concentrations shown as "<" indicate that all wells measured were less than the indicated method detection limit.
b. Where concentrations in one or more of the wells used to calculate the average were reported to be below the detection limit, a value of ½ of the detection limit was used in calculating the average.
c. Data from duplicate samples collected on any given day were averaged before being used in the calculations.

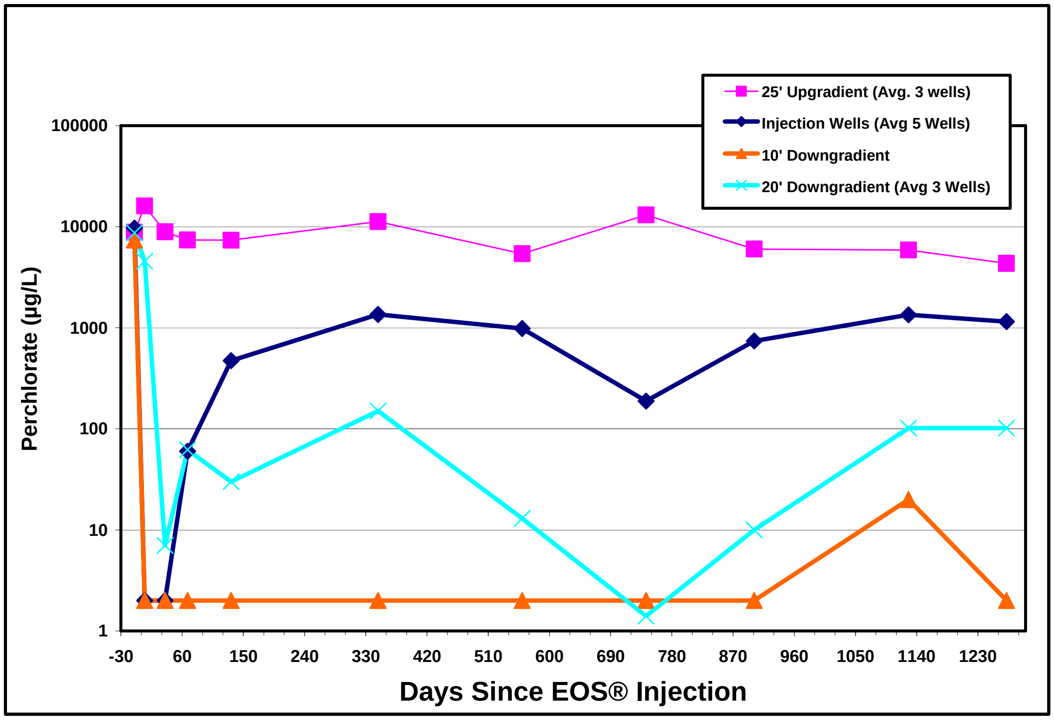

Figure 4-2. Perchlorate Concentrations vs. Time

4.3.1.1 Upgradient Monitor Wells

Prior to injection, perchlorate concentrations across the entire pilot test area averaged 9,330 µg/L (average of 16 wells). Upgradient perchlorate concentrations fluctuated during the extended monitoring period, but no evidence of biodegradation was observed. The average upgradient concentrations ranged from 13,100 to 4,333 µg/L over the 24-month extended monitoring period (**Table 4-4**).

4.3.1.2 Injection Wells

The injection of substrate caused a precipitous drop in perchlorate concentration both in the immediate injection zone and up to 20 ft downgradient of the PRB. No monitoring beyond 20 ft downgradient was performed to evaluate impacts further downgradient. Concentrations in all injection wells were non-detect (<4 µg/L) within 5 days of injection. Perchlorate removal efficiency remained greater than 93% for 133 days in the five injection wells that were measured. Some differences in removal efficiency were noted between injection wells at the ends of the PRB (IW-1 and IW-10) compared to wells in the center of the PRB (IW-3, IW-5 and IW-7) as a result of edge effects resulting from placement of the pilot-scale PRB in the middle of a much larger plume.

The data suggest that the effectiveness of perchlorate degradation may have been starting to decline by 18 months (Day 560) post-injection. However, when the downgradient recovery system was shut down in May 2005 (Day 584), perchlorate removal efficiency increased and remained high for an additional year while the system and groundwater migrated through the barrier under the natural hydraulic gradient. When the system was restarted and groundwater flow velocity increased, perchlorate removal efficiency decreased. By Day 1272, the average

perchlorate concentration in the downgradient wells was 128 µg/L indicating an average removal efficiency of 97% (**Table 4-4).** These data strongly suggest that there was sufficient residual carbon in the PRB for 2.5 to 3 years and that although the biodegradation of perchlorate is rapid, additional contact time in the PRB (when the groundwater flow velocity was slower) resulted in higher removal efficiencies.

4.3.1.3 Downgradient Monitor Wells

Emulsified oil is distributed in a diffuse area extending up to 10 ft downgradient of the injection wells. Consequently, the monitor wells located 20 ft downgradient of the injection wells should more accurately reflect the full extent of biodegradation achieved in the PRB.

Monitoring results indicate that approximately one month was required for groundwater treated through in the PRB to reach the three monitor wells (SMW-4, SMW-6, and SMW-7) 20 ft downgradient (**Figure 4-2**). Consequently, on Day 35 post-injection, the average perchlorate concentration dropped to 8 µg/L (99.9% reduction) in these three wells. The individual well data provided in **Appendix A, Table A-2** show that wells closer to the PRB (i.e., MW-6 and SMW-4 located 7.5 and 12.5 ft downgradient, respectively) were affected even sooner. By Day 5, no concentrations of perchlorate above the method detection limit were measured in these two wells. In both SMW-4 and SMW-7, after non-detectable levels were achieved, perchlorate remained non-detect (<4 µg/L) for the remainder of the 42-month performance monitoring period except for one detection in SMW-4 of 20 µg/L on Day 1126.

4.3.1.4 Mass Removal and Discussion

The installation of the PRB using EOS® effectively reduced the concentration of perchlorate to below both the Federal guideline of 24.5 µg/L and likely the MDE "health advisory limit" of 1 µg/L, although the latter was difficult to demonstrate definitively because it is below the method detection limit for EPA Method 314.1 used in the analyses. As shown in **Table 4-4** and plotted on **Figure 4-2**, the beginning of a perchlorate "rebound" in the injection wells was observed after about 4 months (Day 132), but concentrations stabilized and removal efficiency remained high for the following 7 months. When the contact time in the PRB increased due to the shutdown of the downgradient groundwater recovery system, perchlorate removal increased further. Since TOC was still elevated during this period, it appears that the primary explanation for the apparent inability of the substrate to continue to maintain the high removal efficiencies achieved during the first four months may be insufficient contact time in the PRB. Other contributing explanations may include subsurface heterogeneity affecting the uniformity of the PRB, and also a result of averaging the data. Some injection wells performed better and longer than others demonstrating the effectiveness of the technology, but emphasizing the importance of the layout and design. Depletion of TOC in the injection wells by 42 months may be contributing to the further drop in effectiveness measured during the last sampling event. Additional sampling events would be required to definitively determine if perchlorate concentrations were beginning to climb toward pre-test levels suggesting that the PRB had totally exhausted its useful life and EOS® needed to be re-injected to re-establish the earlier level of effectiveness.

To evaluate the mass of perchlorate removed by the PRB, Solutions-IES compared the average concentrations in the three wells 25 feet upgradient to the average concentrations in the three wells 20 feet downgradient over the course of the 24-month extended monitoring period. Assuming that the barrier is 50 feet wide perpendicular to groundwater flow and 10 feet high vertically, the effective porosity is 0.18, and the average groundwater velocity is 400 ft/year, the flux through the barrier was calculated to be 99 ft^3/day or approximately 2,800 L/day (740 gal/day). The mass flux calculations are summarized in **Table 4-5** and indicate approximately 32 lbs of additional perchlorate were removed during the 24-month extended monitoring period. Overall, approximately 61 lbs of perchlorate were removed over the entire 42-month demonstration.

The removal of 61 lbs of perchlorate by the PRB resulted in “clean, remediated” water in the aquifer downgradient of the PRB. Ultimately, this is the most important outcome. The results in the three monitoring wells located 20 ft downgradient of the barrier showed one to two log orders of magnitude lower concentrations than concentrations actually in the PRB for the life of the study. This further attests to the effectiveness and longevity of the emulsified oil treatment process for treating perchlorate contaminated groundwater.

Table 4-5
Perchlorate Mass Removal

Sample Date	Days (Months) Since Injection		Average Upgradient (µg/L)	Average Downgradient (µg/L)	Change (µg/L)	Change %	Mass removed (lbs/day)	Mass removed [1] (lbs)
10/14/03	5	(~0.1)	32,800	4,567	28,233	86.1%	0.173	0.87
11/13/03	35	(~1)	8,900	7	8,893	99.9%	0.055	1.64
12/16/03	68	(~2)	7,400	62	7,338	99.2%	0.045	1.49
2/19/04	133	(~4)	7,367	30	7,337	99.6%	0.045	2.93
9/21/04	348	(~11)	11,233	150	11,083	98.7%	0.068	14.64
4/21/05	560	(~18)	5,400	13	5,387	99.8%	0.033	7.02
10/20/05	742	(~24)	13,100	1.4	13,099	100.0%	0.080	14.65
3/28/06	901	(~30)	6,000	10	5,990	99.8%	0.037	5.85
11/9/06	1127	(~36)	5,880	102	5,778	98.3%	0.036	8.02
4/3/07	1272	(~42)	4,333	102	4,231	97.6%	0.026	3.77
Total Mass of Perchlorate Removed by Emulsified Oil PRB =								**60.9**
Overall Average[2]			***7,735***	***53***	***7,682***	***99.31%***	***0.047***	***60.0***
Weighted Average[2]			***7,740***	***62***	***7,678***	***99.20%***	***0.047***	***60.0***

Notes:
1. Calculated as mass removed (lbs/day) times the number of days between each sampling event.
2. Does not include data from the first post-injection sampling event.

4.3.2 Chlorinated Ethanes

The average concentrations for 1,1,1-TCA and its biodegradation daughter products in the upgradient, injection and downgradient monitoring wells are summarized in **Table 4-6.** The concentration data for individual wells are provided in the **Appendix A, Table A-3**.

Table 4-6
Biodegradation of 1,1,1-Trichloroethane in EOS® Biobarrier

Well ID (Distance from barrier)	Sample Date	Days (Months) after Injection		1,1,1-Trichloroethane (µg/L)	1,1-Dichloroethane (µg/L)	Chloro-ethane (µg/L)	Cl #
UPGRADIENT MONITORING WELLS							
Average of 3 Monitor Wells 25 feet Upgradient of Biobarrier	9/30/03	-9		16,000	45	<10	3.0
	10/14/03	4	(~0.1)	13,333	217	<10	3.0
	11/13/03	35	(~1)	7,100	207	<10	3.0
	12/16/03	68	(~2)	8,967	10	<10	3.0
	2/19/04	133	(~4)	7,500	42	<10	3.0
	9/21/04	348	(~11)	6,467	37	<2.5	3.0
	4/21/05	560	(~18)	4,700	61	<2.5	3.0
	10/19/05	741	(~24)	4,433	73	<2.5	3.0
	3/27/06	900	(~ 30)	1,167	36	<2.5	3.0
	11/9/06	1126	(~36)	4,567	47	<2.5	3.0
	4/3/07	1272	(~42)	3,700	98	<2.5	3.0
INJECTION WELLS							
Average of 5 Injection Wells in Biobarrier	9/30/03	-9		8,220	32	<2.5	3.0
	10/14/03	4	(~0.1)	1,616	71	<2.5	2.9
	11/13/03	35	(~1)	6,120	133	<2.5	3.0
	12/16/03	68	(~2)	1413	1,119	<2.5	2.5
	2/19/04	133	(~4)	3150	2,320	510	2.3
	9/21/04	348	(~11)	2,686	922	718	2.2
	4/21/05	560	(~18)	1,400	255	398	2.2
	10/19/05	741	(~24)	333	258	559	1.6
	3/27/06	900	(~ 30)	248	86	128	2.0
	11/9/06	1126	(~36)	1,532	212	81	2.7
	4/3/07	1272	(~42)	1,956	114	25	2.9
DOWNGRADIENT MONITORING WELLS							
Average of 3 Monitor Wells 20 feet Downgradient of Biobarrier	9/30/03	-9		12,167	30	<10	3.0
	10/14/03	4	(~0.1)	12,000	162	<10	3.0
	11/13/03	35	(~1)	10,633	59	<10	3.0
	12/16/03	68	(~2)	559	4,175	<10	2.1
	2/19/04	133	(~4)	1,497	2,163	4,600	1.4
	9/21/04	348	(~11)	1,072	1,222	1,060	1.8
	4/21/05	560	(~18)	520	503	1,033	1.5
	10/19/05	741	(~24)	213	220	710	1.4
	3/27/06	900	(~ 30)	240	150	110	2.0
	11/9/06	1126	(~36)	1,863	233	46	2.8
	4/3/07	1272	(~42)	1,030	162	84	2.6

a. Concentrations shown as "<" indicate that all wells measured were less than the indicated method detection limit.
b. Where concentrations in one or more of the wells used to calculate the average were reported to be below the detection limit, a value of ½ of the detection limit was used in calculating the average.
c. Data from duplicate samples collected on any given day were averaged before being used in the calculations.

4.3.2.1 Upgradient Monitor Wells

A description of contaminant concentrations in the upgradient monitor wells during the initial 18-month pilot test can be found in the *Technical Report* (Solutions-IES, 2006). During the 24-month extended monitoring period, the average 1,1,1-TCA concentrations fluctuated between 1167 and 4567 µg/L in the upgradient monitor wells (**Table 4-6**) with individual concentrations ranging between 700 µg/L and 6,600 µg/L (**Appendix A, Table A-3**). In general, over the course of the entire 42-month pilot test, the upgradient 1,1,1-TCA concentrations in groundwater moving into the PRB decreased gradually although there was no supporting evidence of natural biodegradation upgradient of the PRB (i.e., there were no corresponding increases in daughter products). The average concentrations of 1,1-dichloroethane (1,1-DCA) increased to just over 200 µg/L in the first month of the project, but then decreased and stayed between 10 and 98 µg/L over balance of the 42-month test period. No chloroethane was detected in groundwater upgradient of the barrier. 1,1-Dichloroethene (1,1-DCE), an abiotic degradation product of 1,1,1-TCA, was more predominant than any of the biodegradation daughter products with concentrations ranging from 88 to 1,200 µg/L (**Appendix A, Table A-3**). These results typical of groundwater upgradient of the PRB are illustrated in **Figure 4-3** by data from monitor well SMW-2.

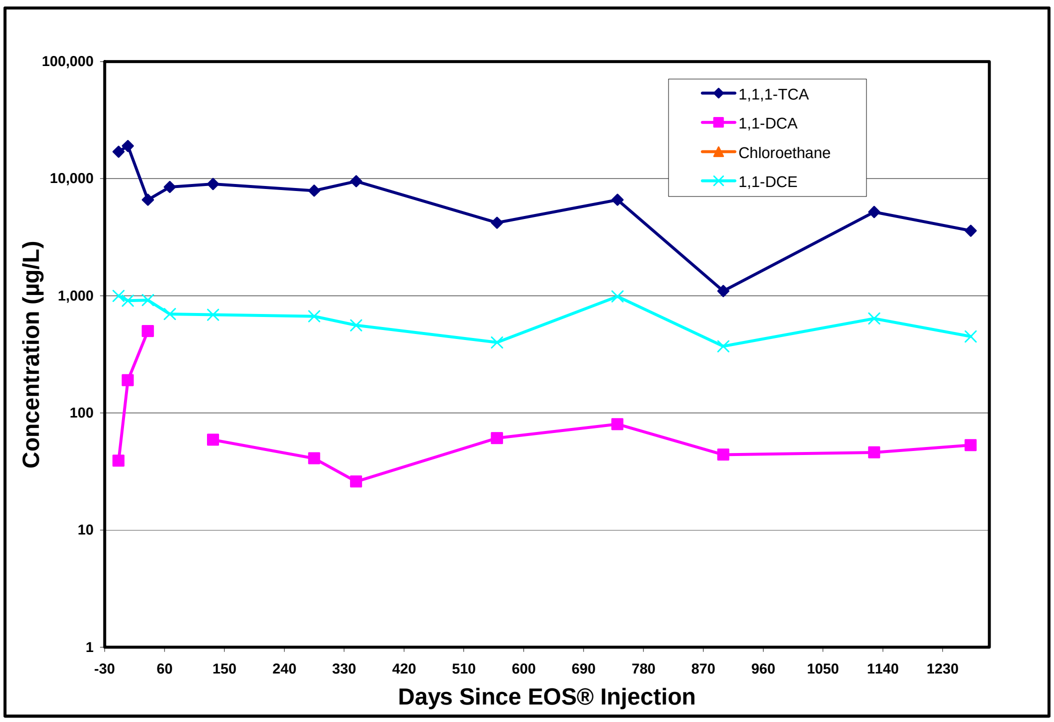

Figure 4-3. Chlorinated Ethane Concentrations vs. Time in Upgradient Monitor Well SMW-2

4.3.2.2 Injection Wells

Performance monitoring was conducted throughout the entire 42-month program on five of the ten injection wells (IW-1, IW-3, IW-5, IW-7 and IW-10). The changes in contaminant concentrations during the initial 18-month pilot test are discussed in the *Technical Report* (Solutions-IES, 2006). On **Table 4-6**, it is apparent that through 18 months, the average 1,1,1-TCA concentrations in the PRB got as low as 1,400 µg/L with a corresponding increase and then decrease of 1,1-DCA and an increase in chloroethane. Concentrations of 1,1,1-TCA continued to decrease for an additional year through Day 900. The treatment efficiency for 1,1,1-TCA declined when the groundwater extraction system was restarted resulting in a greatly reduced contact time in the PRB. This decline in degradation capacity coincided with the decline in TOC in the injection wells to below 5 mg/L (**Table 4-2**).

Figure 4-4 illustrates the changes in concentrations of chlorinated ethane compounds over time in injection well IW-5, which is located in the middle of the PRB. The rapid initial decrease was most likely due to absorption of the dissolved chlorinated ethane molecules into the oil and/or dilution, since no substantial corresponding increases in daughter products were observed (**Appendix A, Table A-3**). Concentrations of 1,1,1-TCA then decreased in IW-5 from starting concentrations as high as 10,000 µg/L to 1,200 µg/L after 18 months (Day 560). When the downgradient groundwater recovery system was shut down on Day 584 and the groundwater flow velocity through the PRB slowed, contact time increased and the degradation improved to its greatest efficiency (515 µg/L on Day 741 and 330 µg/L on Day 1126 in IW-5). After the recovery system was re-started and groundwater flow velocity increased, 1,1,1-TCA was not removed as effectively and rebounded to over 2,000 µg/L.

By 4 months after injection, a sharp increase in the daughter product, chloroethane, was observed in IW-1 and IW-3 and measurable concentrations of chloroethane were detected in all injection wells by 11 months post-injection. The persistence of intermediate daughter products in these wells indicates that complete degradation has not occurred. Nonetheless, substantial degradation of 1,1,1-TCA was achieved within the PRB. The average concentration of 1,1,1-TCA was reduced by 76% from the starting concentration, even after 42 months (**Table 4-6**). With increased contact time in the PRB, higher efficiencies could be achieved.

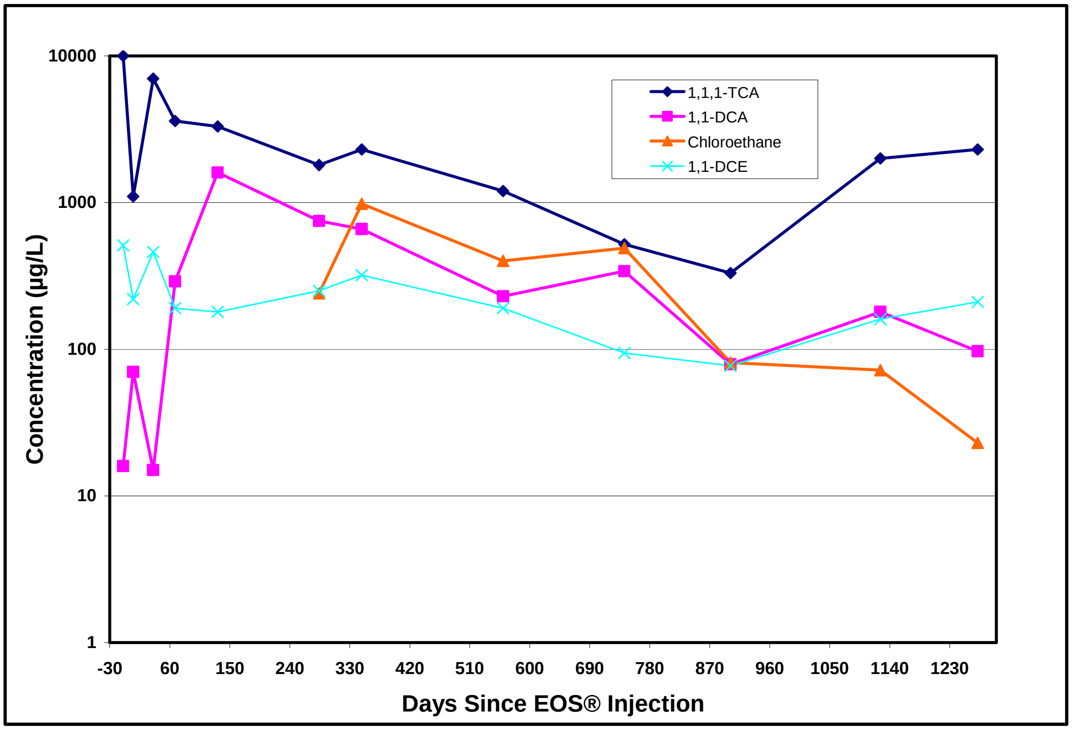

Figure 4-4. Chlorinated Ethane Concentrations vs. Time in Injection Well IW-5

4.3.2.3 Downgradient Monitor Wells

The concentration changes of chlorinated ethane compounds in the downgradient monitor wells follow the same pattern as observed in the injection wells. Changes in groundwater contamination treated in the PRB are reflected 20 feet downgradient approximately two months later as a result of groundwater flow velocity and travel time of contaminants in the aquifer. After 42 months, 1,1,1-TCA was still reduced by 91% 20 feet downgradient of the barrier. **Figure 4-5** shows the changes in 1,1,1-TCA and its daughter products in SMW-6 located approximately 20 feet downgradient of the injection wells forming the PRB.

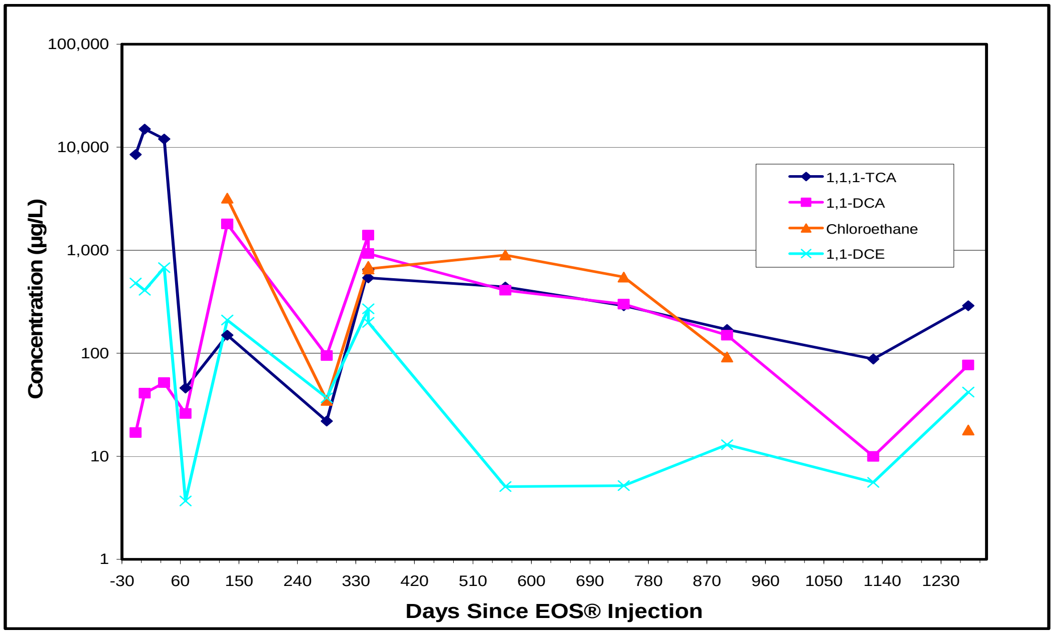

Figure 4-5. Chlorinated Ethane Concentrations vs. Time in Downgradient Monitor Well SMW-6

Although the concentrations of the parent molecule 1,1,1-TCA were dramatically reduced by passage through the PRB and averaged better than 75% lower both in and downgradient of the barrier for over 2.5 years (~30 months), the lowest concentrations achieved did not meet the Federal MCL of 200 µg/L. When the contact time in the PRB was extended, the treatment came closest to meeting the standard. In addition, the active biodegradation of 1,1,1-TCA resulted in the formation of 1,1-DCA at concentrations greater than the Maryland Cleanup Standard of 80 µg/L and chloroethane at concentrations greater than the Cleanup Standard of 3.6 µg/L (**Table 2-1**). To achieve these lower target concentrations would require additional contact time in the PRB for further biodegradation of the parent and daughter compounds to continue.

4.3.2.4 TCA Chlorine Number

Table 4-6 and **Figure 4-6** show the variation in average TCA chlorine number (Cl#) versus time in the upgradient, injection and downgradient wells. TCA chlorine number is calculated as

$$\text{Cl\#} = \frac{3\,[\text{1,1,1-TCA}] + 2\,[\text{1,1-DCA}] + 1\,[\text{CA}]}{[\text{1,1,1-TCA}] + [\text{1,1-DCA}] + [\text{CA}]}$$

where [ ] indicates concentration in moles per liter. Prior to EOS® injection, the TCA Cl# was 3.0 in the upgradient, injection and downgradient wells. In the upgradient wells, TCA Cl# remained constant over time indicating no appreciable reductive dechlorination. However, in the injection and downgradient wells, TCA Cl# decreased following substrate injection. TCA Cl# reached a minimum of 1.6 in the injection wells and 1.4 in the downgradient wells at 741 days, then began to increase. This suggests depletion of the injected substrate is resulting in a loss of barrier treatment efficiency. These results illustrate that during the first 2.6 years (~30 months)

of operation, 1,1,1-TCA was being biodegraded to 1,1-DCA and then chloroethane as groundwater migrated through the EOS® PRB.

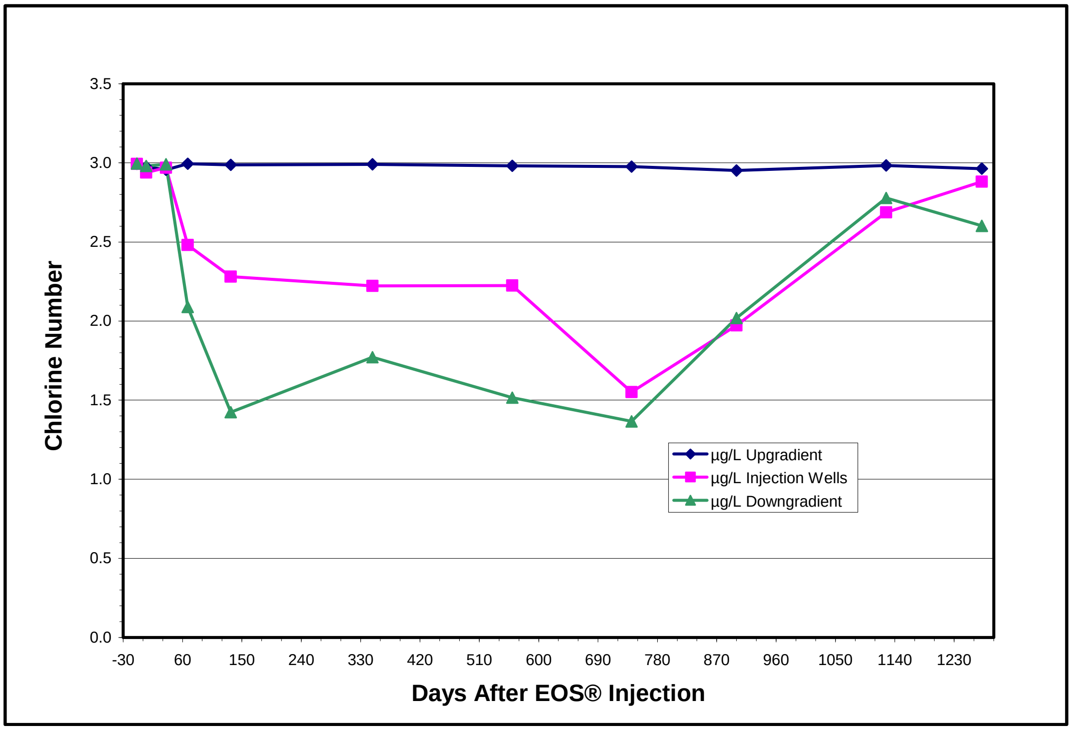

Figure 4-6. Chlorine Number for Chlorinated Ethanes vs. Time

4.3.2.5 Mass Removal

The mass of 1,1,1-TCA removed by the PRB was evaluated by comparing the average concentrations in the three wells 25-feet upgradient to the average concentrations in the three wells 20-feet downgradient over the course of the 24-month pilot test using the same assumptions as indicated above for perchlorate. The mass flux calculations are summarized in **Table 4-7** and indicate that the barrier removed a total of approximately 17.6 lbs of 1,1,1-TCA during the initial 18 months and then 11.5 lbs additional 1,1,1-TCA during the 24-month extended monitoring period. Overall, the PRB removed 29.1 lbs of 1,1,1-TCA during the 42-month pilot study.

Table 4-7
1,1,1-Trichloroethane Mass Removal

Sample Date	Days (Months) Since Injection		Average Upgradient (µg/L)	Average Downgradient (µg/L)	Change (µg/L)	Change %	Mass removed (lbs/day)	Mass removed [1] (lbs)
10/14/03	5	(~0.1)	13,333	12,000	1,333	10%	0.008	0.04
11/13/03	35	(~1)	6,933	10,633	-3,700	-53%	-0.023	-0.68
12/16/03	68	(~2)	8,967	559	8,408	94%	0.052	1.71
2/19/04	133	(~4)	7,500	1,497	6,003	80%	0.037	2.40
9/21/04	348	(~11)	5,933	1,090	4,843	82%	0.030	6.40
4/21/05	560	(~18)	6,467	520	5,947	92%	0.037	7.75
10/20/05	742	(~24)	3,633	213	3,420	94%	0.021	3.82
3/28/06	901	(~30)	3,000	240	2,760	92%	0.017	2.70
11/10/06	1127	(~36)	3,200	1,863	1,337	42%	0.008	1.87
4/3/07	1272	(~42)	4,567	1,030	3,537	77%	0.022	3.13
Total Mass of 1,1,1-TCA Removed by Emulsified Oil PRB =								**29.08**
Overall Average[2]			***5,578***	***1,961***	***3,617***	***65%***	0.022	
1. Calculated as mass removed (lbs/day) times the number of days between each sampling event.								
2. Does not include data from the first post-injection sampling event.								

4.3.3 Chlorinated Ethenes

The concentrations of PCE, TCE, and their daughter products in the individual pilot test wells are provided in **Appendix A, Table A-3.** The baseline concentrations of chlorinated ethenes across the site were substantially less than perchlorate or chlorinated ethanes. Pre-test concentrations of PCE ranged from 25 to 110 µg/L and TCE ranged from 28 to 210 µg/L. The average concentrations in upgradient, injection and downgradient wells are provided in **Table 4-8.** The following subsections discuss the chlorinated ethene results for the upgradient, injection, and downgradient wells during the 42 months of performance monitoring.

4.3.3.1 Upgradient Monitor Wells

Throughout the pilot test, concentrations of chlorinated ethenes fluctuated in the upgradient monitor wells with PCE and TCE being the predominant chlorinated ethenes present. Some low concentrations of *cis*-1,2-DCE were detected, but vinyl chloride (VC) was generally not detected above the laboratory method detection limits. **Figure 4-7** illustrates the chlorinated ethene results in upgradient monitor well SMW-2. As shown in this figure, despite some minor fluctuations over time in the total amount of chlorinated ethenes, the relative amounts of each chlorinated ethene compound remained similar.

Table 4-8
Biodegradation of Tetrachloroethene and Trichloroethene in EOS® Biobarrier

Well ID (Distance from barrier)	Sample Date	Days (Months) After Injection		PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)	Ethene (µg/L)	Cl #
UPGRADIENT MONITORING WELLS									
Average of 3 Monitor Wells 25 feet Upgradient of Biobarrier	9/30/03	-9		81	97	<20	<20	1.2	3.0
	10/14/03	5	(~0.1)	48	120	<20	<20	4.4	2.6
	11/13/03	35	(~1)	21	159	15	<20	0.8	2.7
	12/16/03	68	(~2)	59	233	<20	<20	0.2	3.0
	2/19/04	133	(~4)	64	223	<20	<20	0.1	3.0
	9/21/04	348	(~11)	23	154	14	<5	0.1	2.9
	4/21/05	560	(~18)	6	197	16	<5	0.1	2.9
	10/19/05	741	(~24)	11	188	15	21	0.3	2.6
	3/27/06	900	(~ 30)	7	277	23	18	0.1	2.7
	11/9/06	1127	(~36)	9	189	19	<5	0.1	2.9
	4/3/07	1272	(~42)	7	227	19	9.7	0.2	2.8
INJECTION WELLS									
Average of 5 Injection Wells in Biobarrier	9/30/03	-9		38	102	5	<5	0.1	3.1
	10/14/03	5	(~0.1)	<5	15	4	<5	0.4	2.3
	11/13/03	35	(~1)	29	137	13	<5	0.1	3.0
	12/16/03	68	(~2)	14	29	59	<5	0.2	2.3
	2/19/04	133	(~4)	19	33	78	<5	0.1	2.4
	9/21/04	348	(~11)	13	43	111	10	0.2	2.2
	4/21/05	560	(~18)	<50	62	49	21	6	2.0
	10/19/05	741	(~24)	<5	21	26	33	20	1.0
	3/27/06	900	(~ 30)	<5	93	45	32	11	1.7
	11/9/06	1127	(~36)	<5	70	34	30	6	1.8
	4/3/07	1272	(~42)	<5	170	25	24	3	2.4
DOWNGRADIENT MONITORING WELLS									
Average of 3 Monitor Wells 20 feet Downgradient of Biobarrier	9/30/03	-9		53	103	<20	<20	0.4	2.9
	10/14/03	4	(~0.1)	30	95	<20	<20	0.2	2.8
	11/13/03	35	(~1)	32	160	<20	<20	0.4	2.8
	12/16/03	68	(~2)	<20	<20	137	<20	0.1	2.0
	2/19/04	133	(~4)	25	20	143	<20	0.2	2.1
	9/21/04	348	(~11)	8	21	114	133	0.2	1.5
	4/21/05	560	(~18)	<50	<50	<50	<50	41	0.8
	10/19/05	741	(~24)	<5	8	5	29	31	0.5
	3/27/06	900	(~ 30)	<5	65	16	40	23	1.2
	11/9/06	1127	(~36)	<5	82	27	78	12	1.4
	4/3/07	1272	(~42)	3	115	31	55	5	1.8

a. Concentrations shown as "<" indicate that all wells measured were less than the indicated method detection limit.
b. Where concentrations in one or more of the wells used to calculate the average were reported to be below the detection limit, a value of ½ of the detection limit was used in calculating the average.
c. Data from duplicate samples collected on any given day were averaged before being used in the calculations.

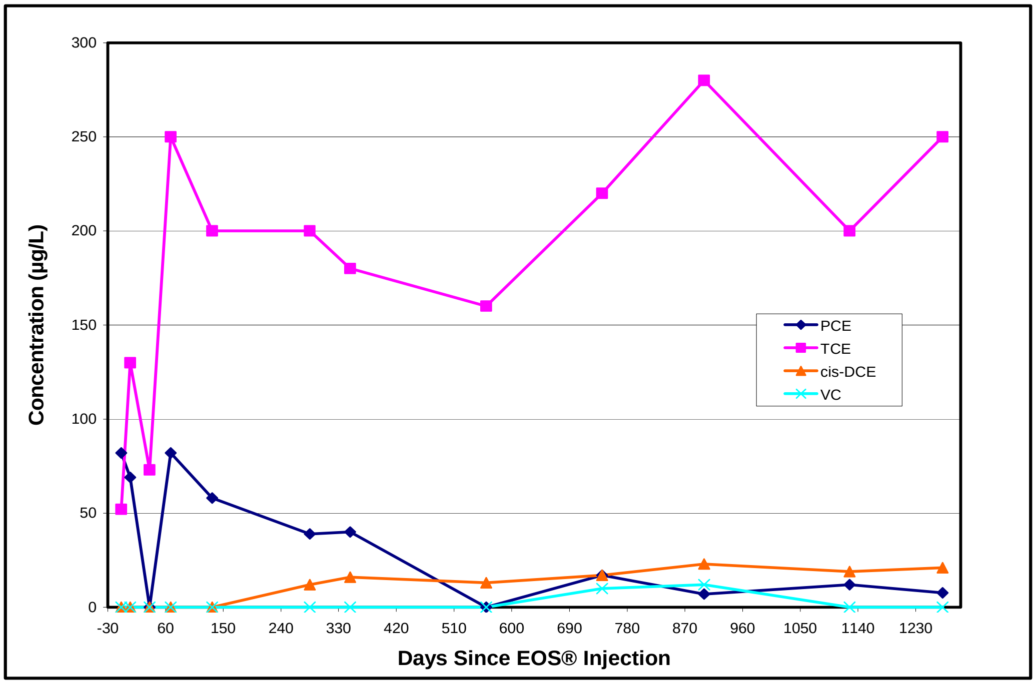

Figure 4-7. Chlorinated Ethene Concentrations vs. Time in Upgradient Monitor Well SMW-2

4.3.3.2 Injection Wells

The presence of 1,1,1-TCA can be inhibitory to Dehalococcoides ethenogenes, which are responsible for the complete degradation of PCE and TCE to ethene (Grostern and Edwards, 2006). The observed biodegradation of PCE and TCE in the PRB is an indicator that these microorganisms are present and active, despite the 1,1,1-TCA in the groundwater. The chlorinated ethene results were similar to those for the chlorinated ethanes. Before injection, the chlorinated ethenes consisted of mostly PCE and TCE. Immediately after injection (Day 5), PCE and TCE concentrations substantially decreased most likely due to sorption to the oil and/or dilution, since no substantial corresponding increases in daughter products were observed. PCE and TCE concentrations rebounded at 1 month post-injection and then reductive dechlorination activity was observed by 2 months post-injection. PCE and TCE concentrations decreased with corresponding production of *cis*-1,2-DCE.

VC was first detected above the laboratory method detection limits in IW-1 and IW-3 after 11 months and in IW-5, IW-7 and IW-10 after 24 months (**Appendix A, Table A-3**). During the initial 11 months of performance monitoring, there was less than 1 µg/L ethene measured in any of the injection wells. At Day 560 (18 months post-injection), the average ethene concentration in the injection wells had increased to 6 µg/L and continued to increase to a maximum of 20 µg/L by 24 months, before beginning to decrease (**Table 4-8**). During the last 24 months of sampling (i.e., the extended monitoring period), the average concentration of TCE began to increase slightly while *cis*-1,2-DCE and VC remained low, but constant.

The chlorinated ethene results for IW-3 are displayed graphically on **Figure 4-8.** This figure demonstrates the initial sorption of the solvents into the oil followed by desorption and subsequent biodegradation illustrating that sorption is a temporary effect and biodegradation is the ultimate reduction mechanism. Because the starting concentrations of PCE and TCE are much lower than 1,1,1-TCA or perchlorate, the impact of increased contact time in the barrier between Day 584 and Day 1064 is not as dramatic. However, as shown in the data in **Appendix A, Table A-3**, a similar effect can be seen.

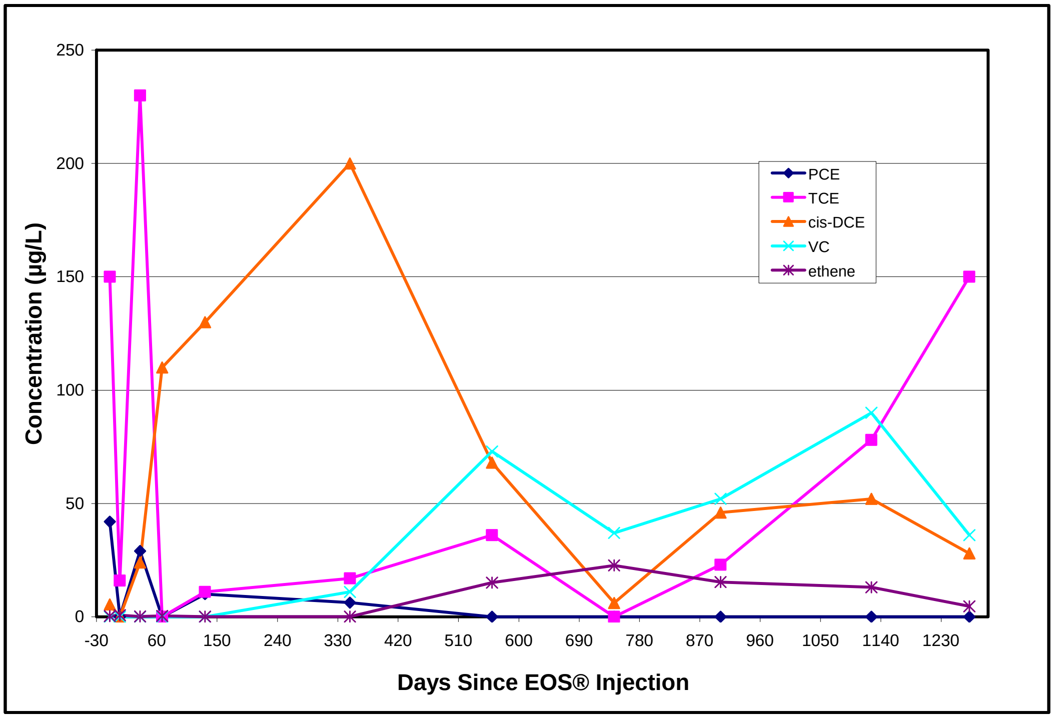

Figure 4-8. Chlorinated Ethene Concentrations vs. Time in Injection Well IW-3.

4.3.3.3 Downgradient Monitor Wells

The results of reductive dechlorination in the PRB were observed in the downgradient monitor wells as groundwater moved through the emulsified oil PRB and the treated water appeared downgradient. As shown in **Table 4-8**, unlike the injection wells, a sharp decrease in PCE and TCE was not observed immediately after injection indicating that the sorption/dilution effects were limited to the vicinity of the injection wells. In general, the downgradient wells showed a decreasing trend in PCE and TCE followed by production of *cis*-1,2-DCE, VC, and ethene over the initial 18 months of monitoring. During the extended monitoring period, PCE did not rebound, but TCE began to increase slowly back toward starting levels. *Cis*-1,2-DCE, VC and ethene all remained measureable, but at low levels.

Figure 4-9 shows the chlorinated ethene results for SMW-6 located 20 feet downgradient of the PRB. This figure illustrates the reduction of PCE and TCE, intermediate production of *cis*-1,2-DCE and VC, and subsequent production of ethene.

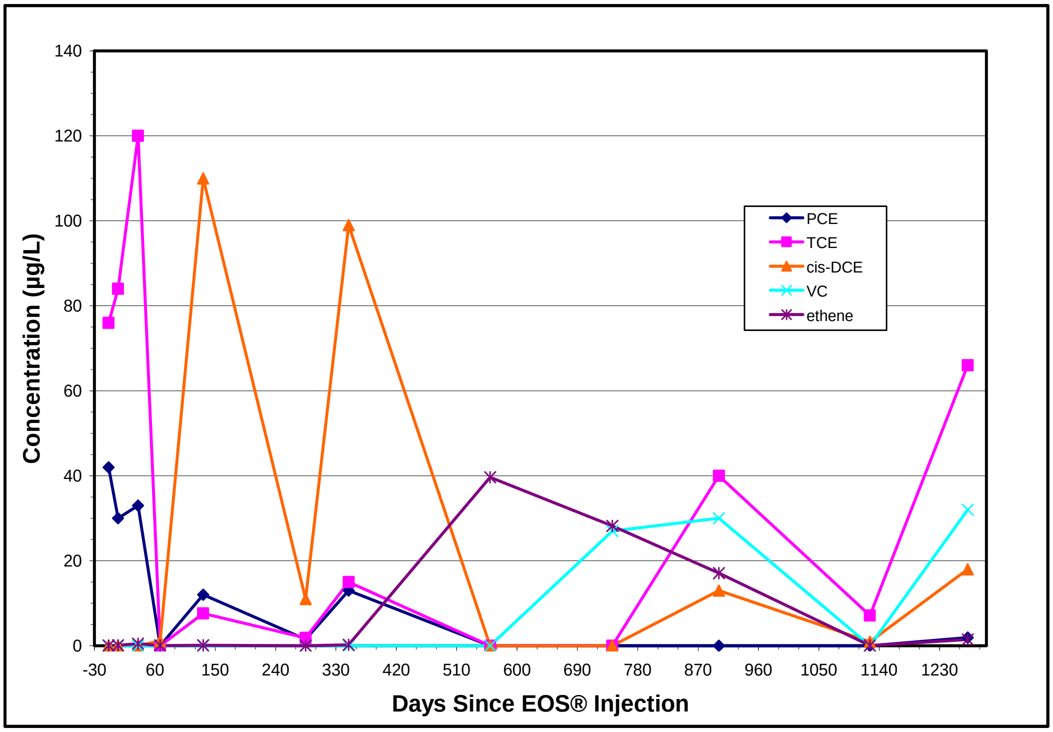

Figure 4-9. Chlorinated Ethene Concentrations vs. Time in Downgradient Monitor Well SMW-6

The data indicate that the PRB was capable of reducing low starting concentrations of PCE to below its MCL of 5µg/L and sustaining these concentrations downgradient of the barrier. The percent removal of TCE in the PRB was substantial, but it appears that the contact time in the barrier was not sufficient to allow for complete biodegradation of TCE to below its MCL of 5 µg/L. Formation of *cis*-1,2-DCE and VC as daughter products further demonstrated the effectiveness of the emulsified oil substrate to enhance reductive dechlorination for an extended period. The formation of ethene is a good indicator that the microbial population in the aquifer has the capacity to metabolize VC to ethene, but additional contact time may be required to complete the biodegradation process.

4.3.3.4 PCE Chlorine Number

Table 4-8 and **Figure 4-10** show the variation in average PCE chlorine number (Cl#) versus time in the upgradient, injection and downgradient wells. PCE chlorine number is calculated as

$$Cl\# = \frac{4\,[PCE] + 3\,[TCE] + 2\,[DCE] + 1\,[VC]}{[PCE] + [TCE] + [DCE] + [VC] + [ethene]}$$

where [ ] indicates concentration in moles per liter. Prior to EOS® injection, the PCE Cl# was 3.3 in the upgradient, injection and downgradient wells. In the upgradient wells, PCE Cl# fluctuated between 2.6 and 3.2 indicating that TCE remained the predominant constituent. In contrast, the PCE Cl# declined to 1.2 in the injection wells and 0.7 in the downgradient wells at 741 days after substrate injection. This large decline in Cl# is due to the conversion of PCE and TCE to 1,2-DCE, VC and ethene. After 741 days, the PCE Cl# began to increase concurrent with start up of the pump and treat system and a decline in groundwater TOC.

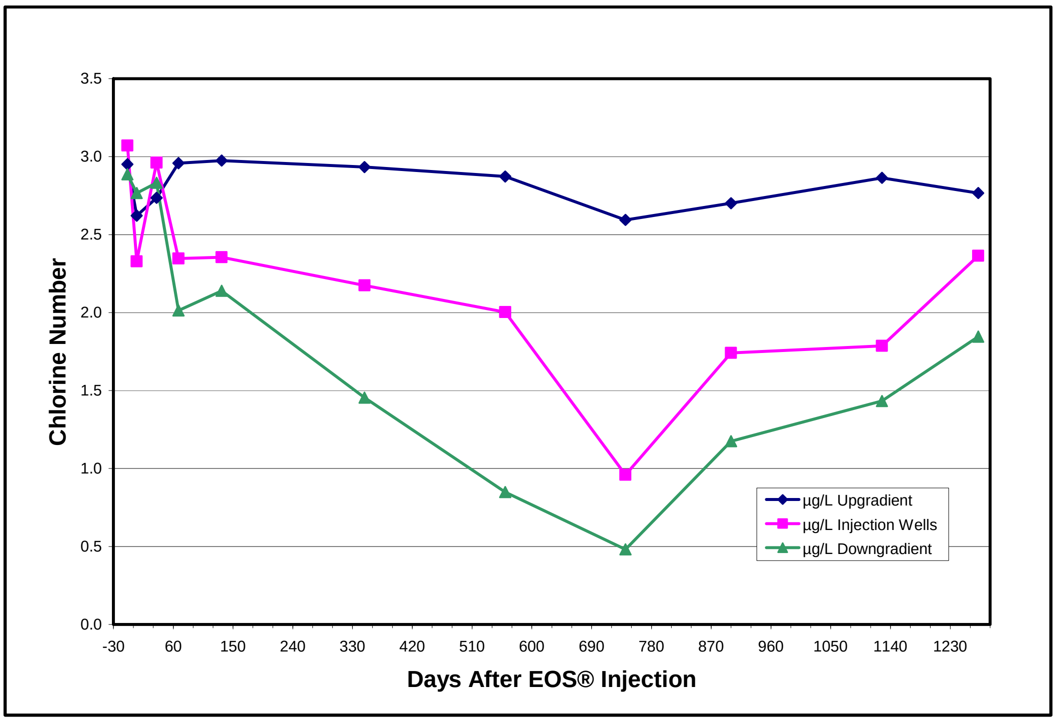

Figure 4-10. Chlorine Number for Chlorinated Ethenes vs. Time.

4.3.4 Biogeochemical Parameters – Competing Electron Acceptors

The goal of the EOS® injection was to create a reducing zone conducive to anaerobic biodegradation of perchlorate and chlorinated solvents. Various parameters indicative of reducing conditions were monitored and evaluated over the course of the demonstration project to aid in interpretation of the contaminant data.

Various electron acceptors can potentially compete with reductive dechlorination, including dissolved oxygen (DO), nitrate, sulfate, iron(III), manganese(IV), and carbon dioxide (methanogenesis). These parameters or their byproducts (e.g., Fe(II), Mn(II), methane) were measured to assess conditions at the site. The analytical results for the biogeochemical parameters that were evaluated at the site are summarized in **Appendix A, Tables A-4** and **A-5** and discussed in the following subsections. A brief discussion of each parameter is provided below.

4.3.4.1 Dissolved Oxygen

In the presence of organic substrate, DO competes with perchlorate as an electron acceptor. Perchlorate-reducing bacteria can be strict anaerobes, microaerophiles or facultative anaerobes (Rikken et al., 1996; Chaudhuri et al., 2002) giving them the ability to grow either in the presence or absence of air, provided proper nutrients are available in the environment. Dehalorespiring bacteria are typically strict anaerobes. DO concentrations <0.5 mg/L are more favorable for anaerobic biodegradation. The DO measurements are shown in **Appendix A, Table A-5**.

The DO concentrations in the 10 injection wells before the EOS® injection averaged 2.9 mg/L. The injection of substrate resulted in a decrease in DO to an average of 1.7 mg/L by Day 68. This lower DO was maintained throughout the pilot test (e.g., 1.3 mg/L at Day 560). At the end of the 42 months, the average DO concentration in the PRB wells was 2.4 mg/L, which may be a response to the limited organic substrate remaining in the PRB by that time. Although the DO concentrations do not indicate strongly anaerobic conditions, the results for the other biogeochemical parameters and for the constituents of concern indicate that the conditions achieved could support anaerobic biodegradation and were maintained for close to 3 years.

4.3.4.2 Nitrate

Nitrate reduction is another indicator of anaerobic conditions favorable for biodegradation. For biodegradation of perchlorate to occur, nitrate must also be depleted because it is a preferential electron acceptor. Similarly, nitrate must be depleted before anaerobic bacteria can use 1,1,1-TCA, PCE or TCE as electron acceptors.

Prior to EOS® injection, the average nitrate concentration in injection wells IW-1, IW-3, IW-5, IW-7 and IW-10 was 9.9 mg/L. Immediately after injection, nitrate was non-detect (<0.5 mg/L) in any of the injection wells (**Appendix A, Table A-4**). Nitrate remained at non-detectable levels in all of the injection wells until the 11-month post-injection sampling event when nitrate was detected in IW-1 at a concentration of 1.5 mg/L. Through Day 742 (24 months post-injection), nitrate was mostly non-detect (<0.5 mg/L). At 30 months, low but measurable concentrations of nitrate began to be recorded. Except at IW-3 in which nitrate stayed below detection for the duration of the test, nitrate concentrations varied between 0.5 and 3.2 mg/L in the PRB. These results are consistent with the observation that the effective life of the emulsion is approximately 2.5 to 3 years.

Figure 4-11 shows the changes in nitrate concentrations during the demonstration in upgradient well SMW-2, injection well IW-3, and downgradient wells SMW-4 and SMW-6. Overall, the EOS® injection quickly resulted in nitrate reducing conditions within and downgradient of the barrier. However, low levels of nitrate started to appear in some of the injection wells near the end of the extended monitoring period indicating that the substrate consumption was decreasing the efficiency of the barrier over time.

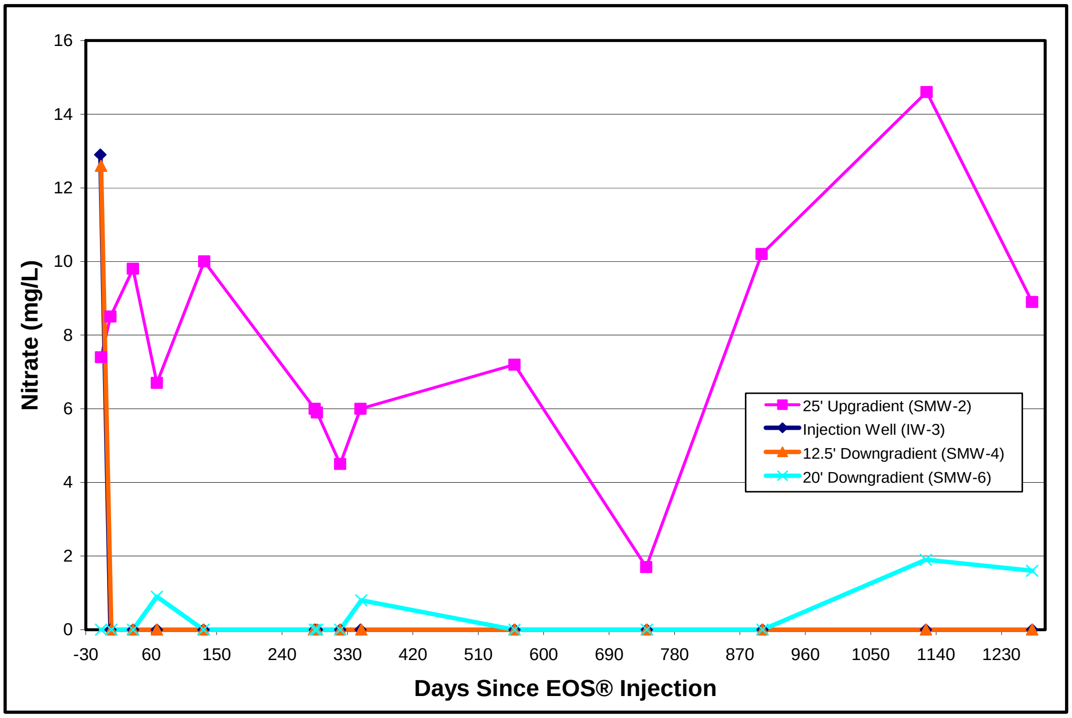

Figure 4-11. Nitrate Concentration vs. Time

4.3.4.3 Sulfate

Sulfate reduction is another indicator of favorable anaerobic conditions. Sulfate can also be used as an electron acceptor for anaerobic processes, but, sulfate reduction generally occurs after DO, nitrate, perchlorate (if present) and iron have been depleted in the microbiological treatment zone. Whereas sulfate concentration greater than 20 mg/L may cause competitive exclusion of anaerobic dehalorespiration of chlorinated solvents, the same is not true for perchlorate.

Sulfate data are provided in **Appendix A, Table A-4**. Sulfate concentrations in representative wells on the site are shown in **Figure 4-12.** Sulfate concentrations were quickly reduced in the injection and downgradient wells. Concentrations in the upgradient wells remained between 16 and 42 mg/L. Near the end of the first 24 months (Day 742) post-injection, sulfate levels in four injection wells (IW-1 was anomalously elevated and not included in the average) and all five downgradient monitor wells averaged 2.4 mg/L. After 742 days, sulfate levels began to rebound in the injection and downgradient wells and had returned to near pre-injection levels of approximately 23 mg/L at 42 months after EOS injection. These results are consistent with the observation that the effective life of the emulsion is approximately 2.5 years.

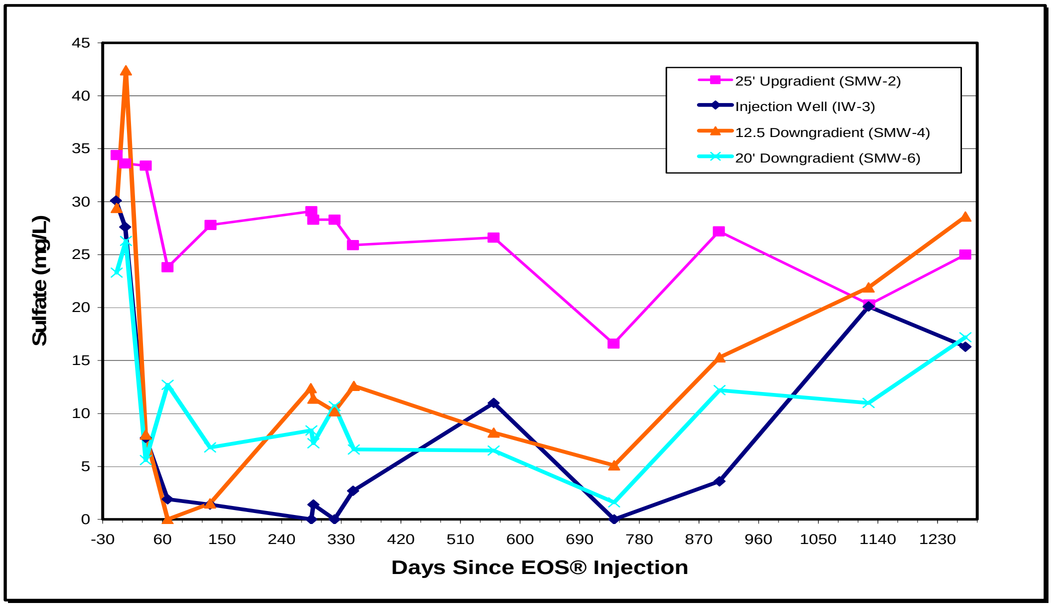

Figure 4-12. Sulfate Concentrations vs. Time

4.3.4.4 Iron and Manganese

Iron and manganese reduction are anaerobic processes. Thus, increases in dissolved iron and dissolved manganese can be indicators of anaerobic biodegradation conditions.

Prior to injection, dissolved iron was not detected (<0.5 mg/L) in any of the pilot test wells. EOS® injection created iron-reducing conditions as indicated by substantial increases in dissolved iron (Fe^{+2}) in the injection wells with individual concentrations as high as 78 mg/L measured in IW-7 at Day 35 (**Appendix A, Table 4**). Increased levels of dissolved iron were also detected in the downgradient monitor wells, but to a lesser extent than the changes observed in the injection wells.

Manganese reduction was also observed in the PRB area with increases in dissolved manganese (Mn^{+2}) observed in all of the injection and downgradient wells following EOS® injection. The dissolved iron and manganese results in selected wells are depicted graphically on **Figure 4-13** and **4-14**, respectively, to illustrate the overall trends in the data. During the extended monitoring period, iron and manganese levels declined. However, at 42 months after substrate injection, dissolved iron and manganese remain detectable indicating a continued reducing environment.

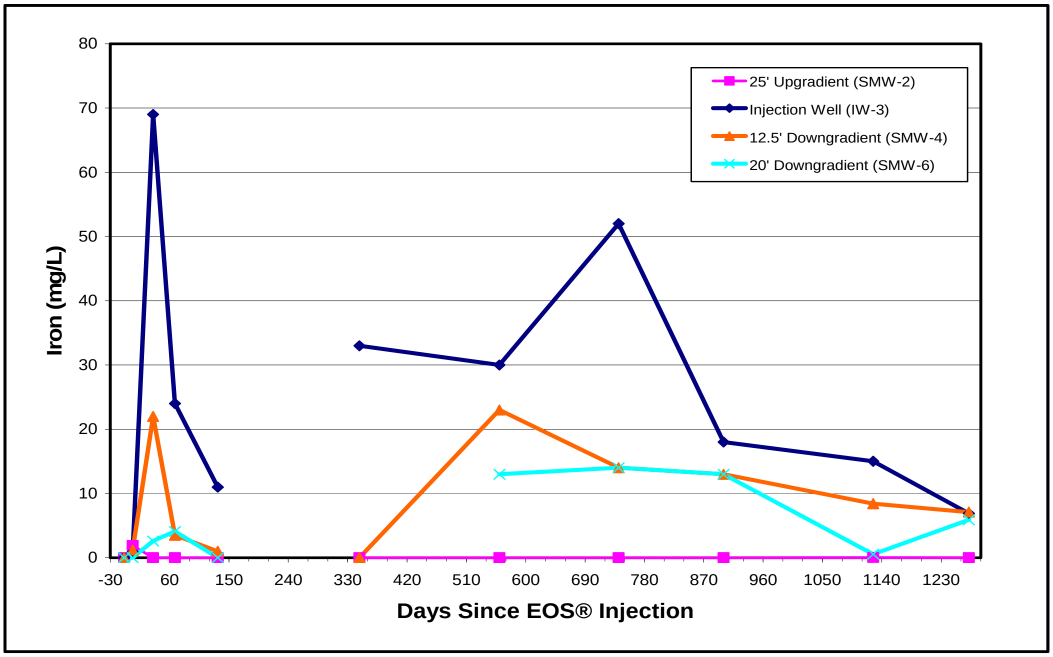

Figure 4-13. Dissolved Iron vs. Time

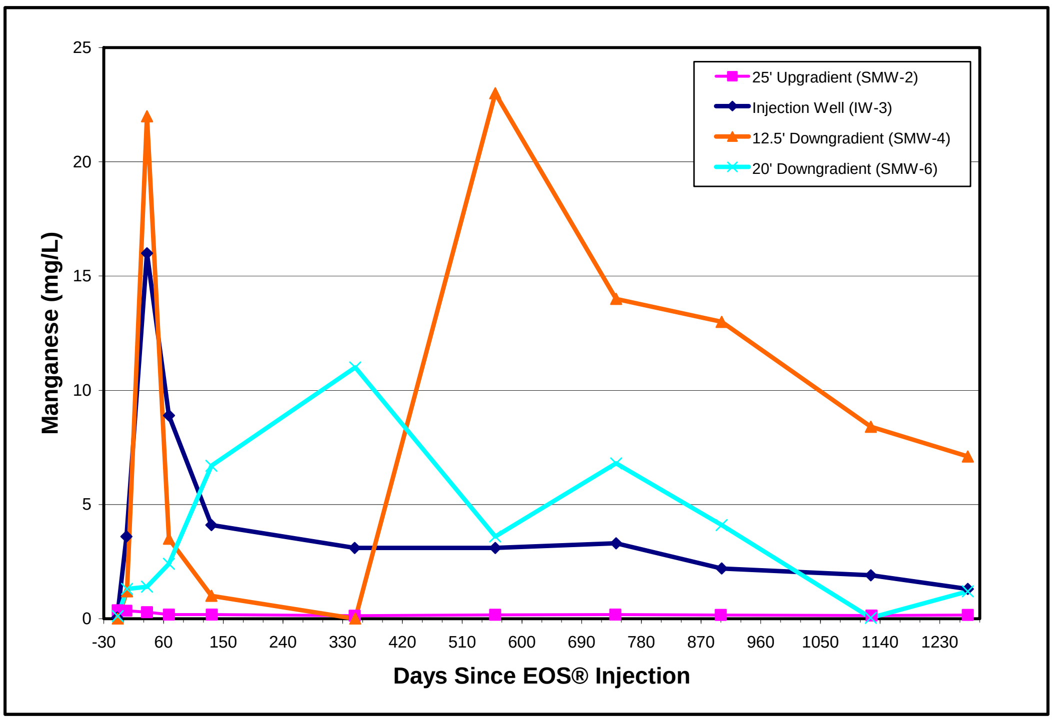

Figure 4-14 Manganese Concentrations vs. Time

4.3.4.5 Methane

Methanogenesis (i.e., the microbial formation of methane from available low molecular weight organic substrates and/or carbon dioxide) occurs in strongly reducing environments generally after nitrate, sulfate, iron and manganese reduction have occurred. The presence of methane above background conditions indicates methanogenesis is occurring and strongly reducing conditions have been established. Before EOS® injection, methane concentrations were <1 µg/L in all of the pilot test wells across the demonstration site. Throughout the entire 42-month pilot test, methane levels remained less than 8 µg/L in all three of the upgradient monitor wells (**Appendix A, Table 4**). In the injection wells, methane generation was observed as soon as 2 months post-injection. Within 11 months, methane concentrations were >1,000 µg/L in all injection wells with concentrations as high as 5,400 µg/L in IW-5. Methane concentrations continued to climb during the active period of the biobarrier extending almost 2.5 years. At that time, the amount of methane produced began to decline suggesting a depletion of organic substrate and loss of reducing capacity in the PRB. **Figure 4-15** presents the methane results in representative wells during the entire 42-month performance monitoring period. Although after 42 months of substrate in the ground there is evidence that its effectiveness is declining, average methane concentrations still exceed 1,000 µg/L in the injection and downgradient wells indicating some level of anaerobic, reducing conditions was being maintained.

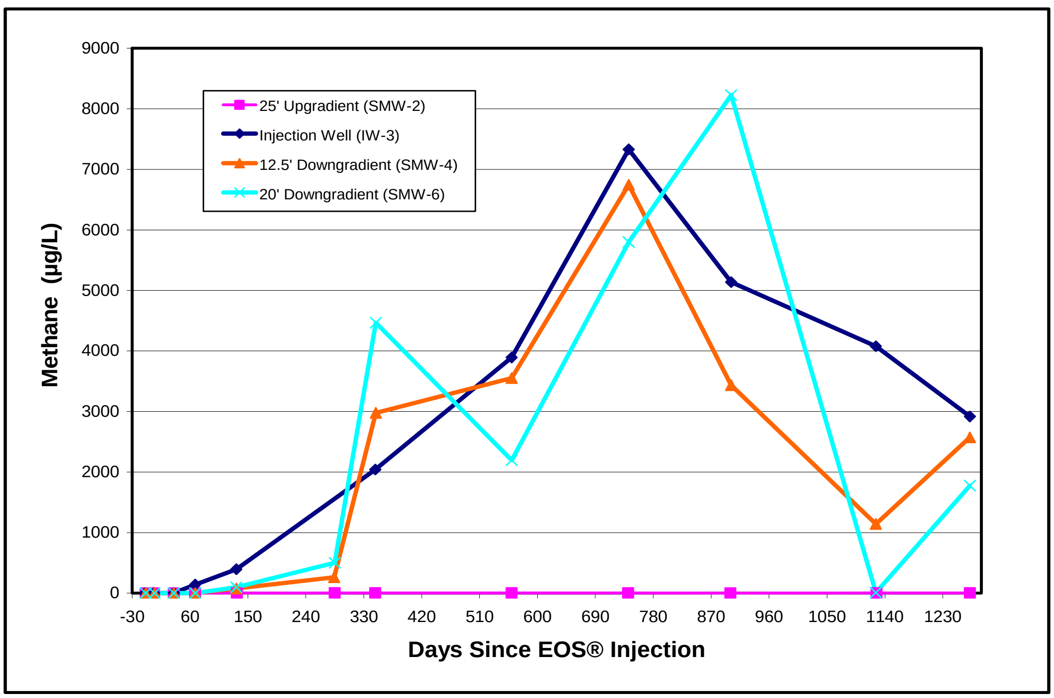

Figure 4-15. Methane Concentrations vs. Time

4.3.5 Indicator Parameters

Parameters that are indicators of conditions favorable for anaerobic biodegradation of perchlorate and chlorinated solvents include ORP and pH. These parameters were evaluated as part of the demonstration project, and the results are discussed below.

4.3.5.1 Oxidation-Reduction Potential

The ORP of a groundwater system depends upon and influence rates of biodegradation (Weidemeier et al., 1998). The ORP of groundwater generally ranges from -400 mV to +800 mV. As ORP becomes more negative, conditions become more conducive for different anaerobic processes to occur. The general sequence is shown as:

> Aerobic Respiration (+820 mV) > Denitrification > Manganese Reduction > Perchlorate Reduction (0 to -100 mV) > Iron Reduction > Sulfate Reduction > Methanogenesis (-240 mV)

Perchlorate reduction can occur most favorably between 0 and -100 mV (ITRC, 2005). At ORP levels less than +50 mV, reductive dechlorination pathways are possible; below –100 mV conditions are most conducive for supporting reductive dechlorination pathways. ORP measurements collected from selected representative wells at the site are illustrated in **Figure 4-16.** Data for individual wells are provided in **Appendix A, Table A-5.** ORP decreased in all of the downgradient monitoring and injection wells following EOS® injection and within 1 month of injection, negative ORP values were detected in all injection wells and downgradient monitor wells. After negative (<0 mV) ORP was established in the injection wells along the PRB, the reducing environment was maintained throughout the initial and extended performance monitoring periods. Anomalously, on Day 560 (18 months post-injection), the ORP measurements in nine of the ten injection wells were reported as being positive values (>0 mV), but all returned to negative ORP by the next sampling event 6 months later. The data indicate that even after 42 months (3.5 years), the ORP in the injection wells remained conducive to perchlorate and chlorinated solvent biodegradation.

Downgradient of the PRB, reducing ORPs were established within one month of injection. Negative ORP values were maintained in SMW-5 and SMW-7, each 20 feet downgradient of the barrier, throughout the balance of the 42-month monitoring program. The ORP in the three other downgradient wells (SMW-4, SMW-6 and MW-6) became less reducing after 2.5 years of monitoring.

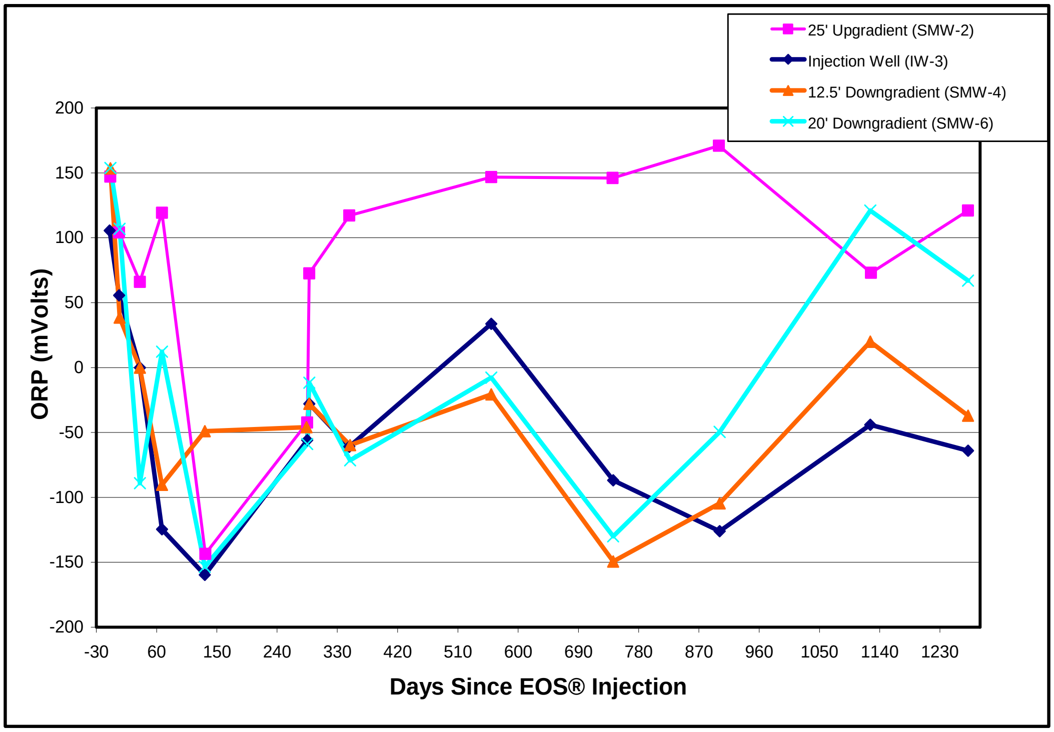

Figure 4-16. Oxidation-Reduction Potential Measurements vs. Time

The ORP values measured in the PRB and downgradient after the injection of emulsified oil substrate to form the PRB reflect conditions adequate to promote biological reduction of DO, nitrate, perchlorate, iron and manganese entering the treatment zone. Some individual ORP measurements suggested that more deeply reducing conditions were established. Although the ORP data are not definitive, the data clearly show impact of the emulsified oil substrate on sulfate reduction, methane production, and ultimately, reductive dechlorination.

4.3.5.2 pH

Values of pH ranging from 6 to 8 standard units (S.U.) are generally preferable for anaerobic biodegradation as the microbial population is sensitive to pH changes. The EOS® concentrate used in the injection has a low pH (~3.5 S.U.); however, over the course of the initial 18-month performance monitoring period, the pH levels in the injection and downgradient monitor wells increased to even more favorable levels from pre-injection levels around pH 6.0 to post-injection readings around pH 6.5 (**Appendix A, Table A-5**). **Figure 4-17** illustrates the changes in pH in representative wells upgradient, and downgradient of the PRB. The pH remained between 6.0 and 7.0 throughout the final 24-month extended monitoring period except for one anomalous drop measured in the downgradient wells on Day 1128. The increase observed within and downgradient of the PRB is likely associated with the reduction of iron and manganese.

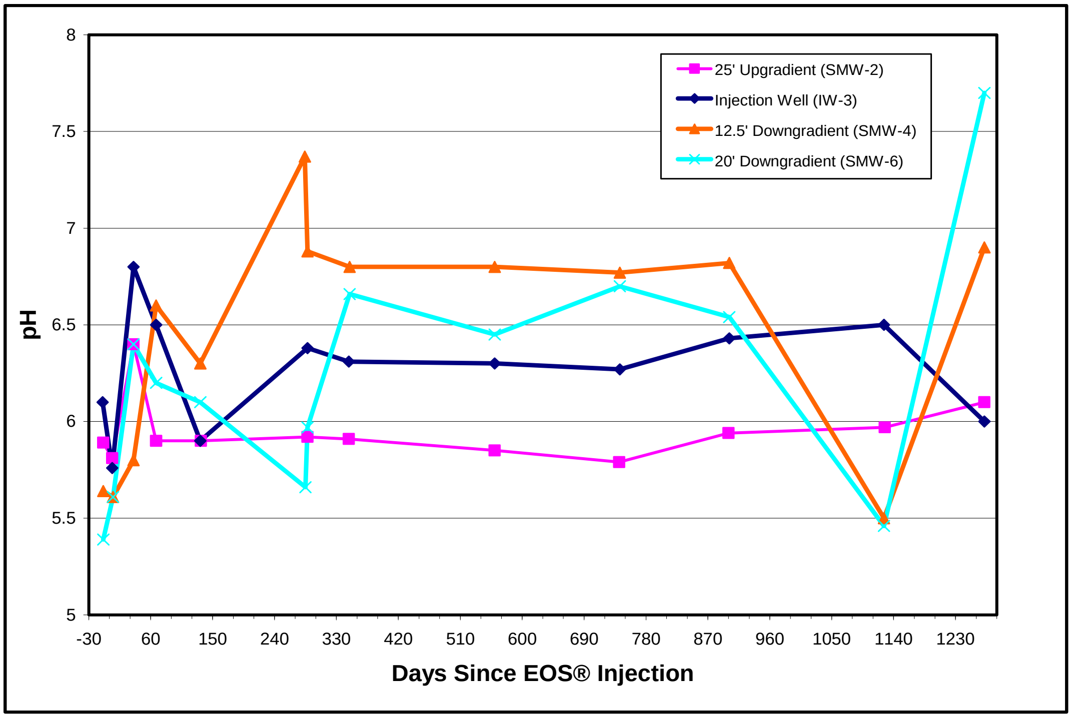

Figure 4-17. pH measurements vs. Time

4.4 Permeability Impacts of the EOS® Injection

The impacts of the emulsified oil substrate injection on aquifer permeability were evaluated by comparing pre- and post-injection hydraulic conductivity values and pre- and post-injection bromide tracer test results. Performance monitoring data were also reviewed to assess permeability impacts. The hydraulic conductivity data are presented in **Table 4-9.** In the upgradient wells, the average hydraulic conductivity essentially remained unchanged during the pilot test, ranging between 0.91 and 8.8 ft/d. Despite the injection of EOS®, the hydraulic conductivity in the biobarrier was never less than the conductivity measured upgradient of the barrier. The average hydraulic conductivity downgradient of the biobarrier was typically higher than both the upgradient and injection wells. In general, hydraulic conductivity was not adversely affected by the introduction of emulsified oil.

Table 4-9
Summary of Hydraulic Conductivity Tests

		Hydraulic Conductivity	
		cm/sec	ft/day
Upgradient Average	Pre-Injection	0.0003	0.91
	4 Months Post-Injection	0.0015	4.25
	18 Months Post-Injection	0.0010	2.93
	24 Months Post-Injection	0.0022	6.13
	30 Months Post-Injection	0.0028	8.01
	42 Months Post-Injection	0.0050	8.80
Injection Well Average	Pre-Injection	0.0141	40.10
	4 Months Post-Injection	0.0045	12.87
	18 Months Post-Injection	0.0029	8.13
	24 Months Post-Injection	0.0034	9.53
	30 Months Post-Injection	0.0042	11.96
	42 Months Post-Injection	0.0039	10.96
Downgradient Average	Pre-Injection	0.0111	31.59
	4 Months Post-Injection	0.0086	24.30
	18 Months Post-Injection	0.0058	16.56
	30 Months Post-Injection	0.0064	18.18
	42 Months Post-Injection	0.0078	24.09

4.5 Summary of Results

The injection of an emulsified oil substrate (EOS®) injection resulted in increased levels of organic carbon in groundwater, resulting in anaerobic conditions and enhanced anaerobic biodegradation of perchlorate, 1,1,1-TCA, PCE and TCE. Total organic carbon (TOC) levels in groundwater increased immediately after EOS® injection as the oil-based substrate sorbed to aquifer sediments, but dissolved TOC and remained elevated for 24 months (2 years) suggesting a constant source of carbon is available to enhance microbial activity for at least that period of time. By 30 months after injection, TOC levels in the injection wells dropped below 5 mg/L, a threshold that would suggest that much of the bioavailable organic carbon had been depleted. Results from a mass balance analysis indicate that 65% of the injected organic carbon had been consumed prior to the decline in TOC indicating relatively efficient use of the injected substrate. However, when the contact time in the PRB was increased between year 2 and 3, some of the highest removal efficiencies for all the contaminants of concern were achieved. This suggests that there is a residual sink of organic carbon adsorbed to the sediment (which is not measurable in the analysis of TOC in the dissolved phase). At 42 months after EOS® injection, 76% of the injected carbon had been accounted for. The continued slow dissolution of the remaining carbon that was sorbed to the aquifer sediments would be expected to provide a continuing source for an even longer period of time, but the final amount and the effect were not measured in this pilot study.

Anaerobic conditions favorable for biodegradation of the target compounds were quickly established in the treatment area. Nitrate and sulfate reduction occurred relatively soon after injection of substrate in both the injection and downgradient wells; dissolved iron (Fe^{+2}) and manganese (Mn^{+2}) concentrations increased indicating iron and manganese reducing conditions had been established. Methane concentrations increased indicating methanogenic conditions within the PRB. No significant changes to the suite of biogeochemical parameters were observed in the upgradient monitor wells.

The single injection of 110 gallons (840 lbs) of EOS® was sufficient to create a 50-ft long PRB that was very effective in stimulating perchlorate biodegradation across a 10-ft vertical interval of the shallow aquifer. Perchlorate concentrations in all of the injection wells were reduced to below detection (<4 µg/L) within 5 days of injection. Maximum removal efficiencies were observed during both the first 4 months and during a period between year 2 and 3 when groundwater flow velocity slowed (due to shutdown of a nearby downgradient groundwater recovery and treatment system) and contact time in the PRB increased. At the end of the extended monitoring period (after 3.5 years), residual TOC was limited and the resumption of normal groundwater flow velocity resulted in drop in perchlorate removal efficiency. Perchlorate concentrations in groundwater that had passed through the PRB were reduced by greater than 97% over the entire 42-month life of the pilot study. Over this 3.5 year period, 76% of the injected substrate had been consumed indicating very efficient substrate utilization.

The PRB also enhanced reductive dechlorination. 1,1,1-TCA, PCE and TCE were biodegraded during transport through the PRB as demonstrated by increases in the concentration of daughter products (1,2-DCA, CA, *cis*-1,2-DCE, VC and ethene) and decreases in chlorine number. Dechlorination efficiency reached a maximum between year 2 and 3, when groundwater flow velocity slowed and contact time in the PRB increased. During the first 24-months when dechlorination was most efficient, 65% of the injected substrate was consumed.

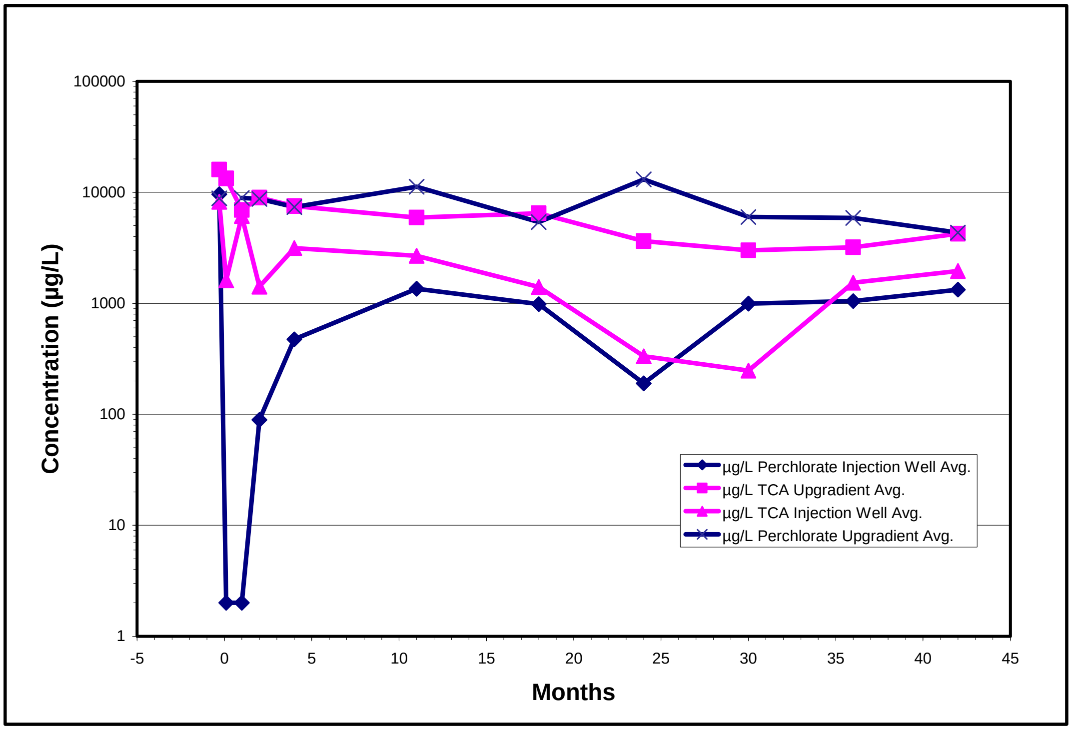

Figure 4-18. Contaminant Concentrations in the PRB during the 42-Month Pilot Study

Based on data collected during the original 18-month pilot test, the effective longevity of the EOS® barrier was estimated to be approximately 2 to 2.5 years. Long term monitoring showed the barrier was effective in treating both perchlorate and chlorinated solvents for 2.5 to 3.5 years. The average hydraulic conductivity downgradient of the biobarrier was typically higher than both the upgradient and injection wells. In general, hydraulic conductivity was not adversely affected by the introduction of emulsified oil. Increased contact time in the PRB was shown to be desirable for both utilizing residual organic substrate and achieving regulatory cleanup goals.

5.0 Cost Assessment

5.1 Cost Reporting

The costs associated with the extended monitoring period are entirely derived from performing four sampling events during the 24-month period. The cost for each event was approximately $12,000. There was no additional O&M necessitated by prolonging the pilot study from 18 months to 42 months. Some additional costs were incurred to prepare this *Extended Monitoring Report*.

5.2 Cost Analysis

5.2.1 Cost Comparison

A detailed cost comparison will be provided in the Cost and Performance Report and will incorporate cost data from the current ATK Elkton demonstration as well as the second demonstration site that was part of this project (ER-0221) at SWMU 17 at the Charleston Naval Weapons Station. Emulsified oils will be compared to iron PRBs and to pump-and-treat systems. As discussed in the *Technical Report* (Solutions-IES, 2006), we estimated the installation costs of a full-scale emulsified oil PRB at the ATK site to be approximately $38,000 which is equivalent to $19/squre foot of barrier or $0.02/gallon treated. A brief cost comparison to alternate technologies can also be found in the *Technical Report.*

5.2.2 Cost Basis

The pilot test PRB at the Maryland perchlorate site treated approximately 740 gallons per day. This barrier cost approximately $23,200 to install and was effective in treating perchlorate and chlorinated solvent impacted groundwater for two years. Over the two year effective life, the barrier treated 540,200 gallons of perchlorate and chlorinated solvent impacted groundwater. Therefore, the pilot-scale PRB cost $0.043/gallon treated or $46/square foot of barrier. The costs for this PRB are higher than expected given the nature of the demonstration project. A closer well spacing was used in the design compared to a full-scale system.

6.0 Implementation Issues

6.1 End-User Issues

Potential end users of the emulsified oil technology include agencies within the federal government (Dept. of Defense, Dept. of Energy, and Environmental Protection Agency), state and local governments, and private industry.

Potential end user concerns may include:

- Possible permeability losses due to injection of the emulsion;
- Potential impact of elevated residual concentrations of daughter products;
- Sorption of the contaminants to the oil versus degradation;
- Secondary water quality issues (e.g., changes to color, taste and odor that might occur);
- Gas production; and
- Longevity of the product at specific sites.

All aforementioned end-user concerns (excluding longevity) were previously addressed in the *Technical Report* (Solutions-IES, 2006). The longevity of the PRB relies heavily on the subsurface lithology and contaminant mass. At the ATK site the PRB performed to reduce the level of contamination to levels compliant with regulatory limits for 2 to 2.5 years. However, this duration may not be an acceptable assumption at all locations where the technology is to be used. Users should rely on specific calculations to guide them in estimating the longevity of the emulsified oil in the subsurface.

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8.0 Points of Contact

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Mr. Charles Smyser	Cecil County Health Department Environmental Health Center 401 Bow St Elkton, MD 21921-5515	(410) 996-5160 (410) 996-5153 csmyser@dhmh.state.md.us	County Contact

APPENDIX A

APPENDIX A, TABLE 1
Total Organic and Inorganic Carbon in Groundwater

Well ID (Distance from Barrier)	Sample Date	Days Since Injection	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Methane (mg/L)	TOC, TIC & Methane (mg/L)
UPGRADIENT MONITORING WELLS						
SMW-1 (25 feet)	9/30/03	-9	1.39	27.9	0.000	29.3
	10/13/03	4	1.95	24.7	0.006	26.7
	11/13/03	35	1.75	22.0	0.000	23.8
	12/16/03	68	0.5	23.9	0.001	24.4
	2/19/04	133	1.12	23.1	0.002	24.2
	9/21/04	348	1.18	24.5	0.005	25.7
	4/21/05	560	1.42	26.1	0.007	27.5
	10/19/05	741	1.66	26.2	0.006	27.9
	3/27/06	900	1.65	9.60	0.000	11.3
	11/8/06	1126	0.5	27.5	0.006	28.0
	4/3/07	1272	1.59	24.8	0.008	26.4
SMW-2 (25 feet)	9/30/03	-9	0.5	20.5	0.001	21.0
	10/13/03	4	1.48	18.2	0.001	19.7
	11/13/03	35	1.62	24.1	0.001	25.7
	12/16/03	68	0.5	22.6	0.001	23.1
	2/19/04	133	0.5	16.4	0.001	16.9
	9/21/04	348	0.5	21.4	0.004	21.9
	4/21/05	560	0.5	22.6	0.002	23.1
	10/19/05	741	1.81	28.4	0.004	30.2
	3/27/06	900	1.35	12.0	0.000	13.4
	11/8/06	1126	1.82	15.3	0.003	17.1
	4/3/07	1272	2.05	22.4	0.003	24.5
SMW-3 (25 feet)	9/30/03	-9	1.08	21.1	0.001	22.2
	10/13/03	4	3.43	18.5	0.000	21.9
	11/13/03	35	1.82	9.77	0.001	11.6
	12/16/03	68	0.5	17.3	0.000	17.8
	2/19/04	133	0.5	14.3	0.000	14.8
	9/21/04	348	0.5	13.3	0.001	13.8
	4/21/05	560	1.28	21.5	0.005	22.8
	10/19/05	741	1.37	13.3	0.018	14.7
	3/27/06	900	1.34	15.2	0.000	16.5
	11/8/06	1126	0.5	14.6	0.001	15.1
	4/3/07	1272	1.43	23.2	0.001	24.6
Average of 3 Monitor Wells 25 ft Upgradient of Biobarrier	9/30/03	-9	0.82	23.2	0.001	**24.0**
	10/13/03	4	2.29	20.5	0.002	**22.8**
	11/13/03	35	1.73	18.6	0.001	**20.4**
	12/16/03	68	0.50	21.3	0.001	**21.8**
	2/19/04	133	0.37	17.9	0.001	**18.3**
	9/21/04	348	0.39	19.7	0.003	**20.1**
	4/21/05	560	0.90	23.4	0.004	**24.3**
	10/19/05	741	1.01	22.6	0.009	**23.7**
	3/27/06	900	1.00	12.3	0.000	**13.3**
	11/8/06	1126	0.33	19.1	0.003	**19.5**

	4/3/07	1272	1.01	23.5	0.004	**24.5**
INJECTION WELLS						
IW-1	9/29/03	-10	1.15	24.2	0.001	25.4
	10/13/03	4	100	42.0	0.000	142.0
	11/13/03	35	62.5	47.7	0.008	110.2
	12/16/03	68	61.8	53.6	0.166	115.6
	2/18/04	132	36.2	29.9	1.047	67.1
	9/21/04	348	17.6	35.4	3.637	56.6
	4/21/05	560	10.8	28.7	3.437	42.9
	10/20/05	742	12.3	49.3	5.477	67.1
	3/28/06	901	1.68	15.5	3.137	20.3
	11/8/06	1126	2.58	30.4	4.257	37.2
	4/3/07	1272	1.69	22.8	1.008	25.5
IW-3	9/29/03	-10	1.15	25.1	0.001	26.3
	10/13/03	4	418	52.8	0.001	470.8
	11/13/03	35	48.4	45.8	0.003	94.2
	12/16/03	68	73.2	51.3	0.142	124.6
	2/18/04	132	49.1	27.6	0.395	77.1
	9/21/04	348	53.2	28.4	2.043	83.6
	4/21/05	560	21.7	29.1	3.891	54.7
	10/20/05	742	47.5	64.6	7.330	119.4
	3/28/06	901	3.02	27.7	5.138	35.9
	11/8/06	1126	2.09	38	4.079	44.2
	4/3/07	1272	1.41	25.5	2.919	29.8
IW-5	9/29/03	-10	0.5	24.0	0.000	24.5
	10/13/03	4	151	43.8	0.001	194.8
	11/13/03	35	25.2	37.1	0.002	62.3
	12/16/03	68	29.3	0.5	0.059	29.9
	2/18/04	132	28.0	24.6	0.136	52.7
	9/21/04	348	52.3	28.6	5.394	86.3
	4/21/05	560	13.1	27.1	2.919	43.1
	10/20/05	742	21.4	56.6	8.475	86.5
(Dup-1)	10/20/05	742	22.9	57.0		
	3/28/06	901	2.26	21.0	5.360	28.6
(Dup-1)	3/28/06	901	2.58	15.3	3.002	20.9
	11/8/06	1126	1.9	30.1		
	4/3/07	1272	2.5	24.1	1.125	27.7
IW-7	9/29/03	-10	1.16	20.6	0.000	21.8
	10/13/03	4	176	39.8	0.001	215.8
	11/13/03	35	89.0	47.8	0.025	136.8
	12/16/03	68	96.9	68.5	0.129	165.5
	2/18/04	132	64.7	32	0.208	96.9
	9/21/04	348	48.8	31.6	4.638	85.0
	4/21/05	560	38.1	37.8	3.879	79.8
	10/20/05	742	29.8	77.4	5.375	112.6
	3/28/06	901	6.08	24.2	4.935	35.2
	11/8/06	1126	3.56	33.8	3.251	40.6
(Dup-1)	4/3/07	1272	2.72	30.5	3.930	37.1
IW-10	9/29/03	-10	0.5	21.0	0.000	21.5
	10/13/03	4	451	38.7	0.000	489.7
	11/13/03	35	39.5	25.9	0.000	65.4
	12/16/03	68	24.8	28.8	0.001	53.6

	2/19/04	133	18.2	25.8	0.018	44.0
	9/21/04	348	29.7	20.5	1.279	51.5
	4/21/05	560	19.0	26.6	1.013	46.6
	10/20/05	742	62.6	42.9	2.287	107.8
	3/28/06	901	5.8	21.2	3.918	30.9
	11/8/06	1126	1.3	23.6	4.438	29.3
	4/3/07	1272	2.4	26.9	3.198	32.5
Average of 5 Injection Wells in Biobarrier	9/29/03	-10	0.7	23.0	0.000	**23.7**
	10/13/03	4	259.2	43.4	0.001	**302.6**
	11/13/03	35	52.9	40.9	0.008	**93.8**
	12/16/03	68	57.2	40.5	0.099	**97.8**
	2/19/04	133	39.2	28.0	0.361	**67.6**
	9/21/04	348	40.3	28.9	3.398	**72.6**
	4/21/05	560	20.5	29.9	3.028	**53.4**
	10/20/05	742	34.7	58.2	5.789	**98.7**
	3/28/06	901	3.8	21.9	4.498	**30.2**
	11/8/06	1126	2.4	28.2	4.006	**34.6**
	4/3/07	1272	2.0	27.2	2.436	**31.6**
DOWNGRADIENT MONITORING WELLS						
MW-6 (7.5 feet)	9/30/03	-9	0.5	21.9	0.000	22.4
	10/14/03	5	48.6	50.6	0.000	99.2
	11/13/03	35	8.7	0.5	0.000	9.2
	12/16/03	68	1.12	32.6	0.002	33.7
	2/18/04	132	8.42	26.6	0.075	35.1
	9/22/04	349	80.2	18.2	5.223	103.6
	4/21/05	560	14.1	27.0	1.464	42.6
	10/20/05	742	3.58	52.5	4.679	60.8
	3/28/06	901	1.79	21.3	4.352	27.4
	11/8/06	1126	0.5	29.1	0.430	30.0
	4/3/07	1272	0.5	21.5	1.345	23.3
SMW-4 (12.5 feet)	9/30/03	-9	0.5	24.0	0.000	24.5
	10/14/03	5	190	44.0	0.000	234.0
	11/13/03	35	14.1	37.0	0.001	51.1
	12/16/03	68	12.6	35.7	0.001	48.3
	2/18/04	132	10.7	28.5	0.076	39.3
	9/22/04	349	21.2	21.1	2.978	45.3
	4/21/05	560	21.4	26.4	3.552	51.4
	10/20/05	742	2.81	50.9	6.747	60.5
	3/28/06	901	1.4	20.10	3.434	24.9
	11/8/06	1126	1.03	26.3	1.142	28.5
	4/3/07	1272	1.34	23.6	2.573	27.5
SMW-5 (20 feet)	9/30/03	-9	0.5	25.4	0.000	25.9
	10/14/03	5	59.8	30.6	0.000	90.4
	11/13/03	35	20.0	60.3	0.001	80.3
	12/16/03	68	11.0	36.3	0.002	47.3
	2/18/04	132	16.8	28.6	0.498	45.9
	9/22/04	349	50.9	24.8	4.150	79.8
	4/21/05	560	22.9	29.0	3.117	55.0
	10/20/05	742	2.44	56.3	6.634	65.4
	3/28/06	901	1.67	22.4	2.561	26.6

	11/8/06	1126	1.1	21.8	1.970	24.9
	4/3/07	1272	2.51	26.1	3.552	32.2
SMW-6	9/30/03	-9	0.5	20.7	0.000	21.2
(20 feet)	10/14/03	5	11.3	27.0	0.000	38.3
	11/13/03	35	11.3	40.5	0.001	51.8
	12/16/03	68	0.5	19.1	0.000	19.6
	2/18/04	132	4.53	24.4	0.097	29.0
	9/22/04	349	29.7	22.4	4.467	56.6
	4/21/05	560	7.80	24.1	2.194	34.1
	10/20/05	742	3.45	55.7	5.797	64.9
	3/28/06	901	1.37	7.77	8.226	17.4
	11/8/06	1126	2.54	11.1	0.009	13.6
	4/3/07	1272	1.48	18	1.777	21.3
SMW-7	9/30/03	-9	0.5	21.7	0.000	22.2
(20 feet)	10/14/03	5	2.36	17.6	0.000	20.0
	11/13/03	35	10.9	61.5	0.000	72.4
	12/16/03	68	4.91	33.6	0.001	38.5
	2/18/04	132	2.01	29.0	0.020	31.0
	9/22/04	349	35.0	25.9	3.002	63.9
	4/21/05	560	19.4	29.1	3.359	51.9
	10/20/05	742	13.5	52.9	4.826	71.2
	3/28/06	901	2.06	0.5	5.187	7.7
	11/8/06	1126	1.2	24.8	1.657	27.7
	4/3/07	1272	2.32	29.8	5.426	37.5
Average of	9/30/03	-9	0.50	22.6	0.000	**23.1**
3 Monitor Wells	10/14/03	5	24.5	25.1	0.000	**49.6**
20 feet Downgradient	11/13/03	35	14.1	54.1	0.001	**68.2**
of Biobarrier	12/16/03	68	5.47	29.7	0.001	**35.1**
	2/18/04	132	7.78	27.3	0.205	**35.3**
	9/22/04	349	38.5	24.4	3.873	**66.8**
	4/21/05	560	16.7	27.4	2.890	**47.0**
	10/20/05	742	6.46	55.0	5.752	**67.2**
	3/28/06	901	1.70	10.2	5.324	**17.2**
	11/8/06	1126	1.61	19.2	1.212	**22.1**
	4/3/07	1272	2.10	24.6	3.585	**30.3**

Concentrations shown in shaded cells are 1/2 the method reporting limit.

APPENDIX A, TABLE 2
Summary of Perchlorate in Groundwater

Well ID (Distance from barrier)	Sample Date	Days Since Injection	Perchlorate (µg/L)	Perchlorate (µM)
UPGRADIENT MONITORING WELLS				
SMW-1	9/30/03	-9	16,000	161.0
(25 feet)	10/14/03	5	72,000	724.3
	11/13/03	35	11,000	110.7
	12/16/03	68	15,000	150.9
	2/19/04	133	11,000	110.7
	9/21/04	348	14,000	140.8
	4/21/05	560	6,900	69.4
	10/19/05	741	24,000	241.4
	3/27/06	900	6,200	62.4
	11/8/06	1126	9,800	98.6
	4/3/07	1272	5,100	51.3
SMW-2	9/30/03	-9	6,100	61.4
(25 feet)	10/14/03	5	23,000	231.4
	11/13/03	35	13,000	130.8
	12/16/03	68	7,900	79.5
	2/19/04	133	6,300	63.4
	9/21/04	348	15,000	150.9
	4/21/05	560	4,900	49.3
	10/19/05	741	14,000	140.8
	3/27/06	900	10,000	100.6
	11/9/06	1127	7,000	70.4
	4/3/07	1272	5,900	59.4
SMW-3	9/30/03	-9	4,400	44.3
(25 feet)	10/14/03	5	3,400	34.2
	11/13/03	35	2,700	27.2
(Dup-1)	11/13/03	35	2,200	22.1
	12/16/03	68	3,300	33.2
	2/19/04	133	4,800	48.3
	9/21/04	348	4,700	47.3
	4/21/05	560	4,400	44.3
	10/19/05	741	1,300	13.1
	3/27/06	900	1,800	18.1
	11/10/06	1128	840	8.5
	4/3/07	1272	2,000	20.1
Average of	9/30/03	-9	**8,833**	**88.9**
3 Monitor Wells	10/14/03	5	**32,800**	**330.0**
25 ft Upgradient	11/13/03	35	**8,900**	**89.5**
of Biobarrier	12/16/03	68	**8,733**	**87.9**
	2/19/04	133	**7,367**	**74.1**
	9/21/04	348	**11,233**	**113.0**
	4/21/05	560	**5,400**	**54.3**
	10/19/05	741	**13,100**	**131.8**
	3/27/06	900	**6,000**	**60.4**
	11/10/06	1128	**5,880**	**59.2**
	4/3/07	1272	**4,333**	**43.6**

INJECTION WELLS				
IW-1	4/23/03	-169	21,000	211.3
	9/29/03	-10	20,000	201.2
	10/14/03	5	2 (U)	<0.04
	11/13/03	35	2 (U)	<0.04
	12/16/03	68	300	3.0
(Dup-1)	12/16/03	68	570	5.7
	2/18/04	132	2,200	22.1
	9/21/04	348	4,200	42.3
	4/21/05	560	3,600	36.2
	10/20/05	742	880	8.9
	3/28/06	901	2,200	22.1
	11/9/06	1127	3,700	37.2
	4/3/07	1272	3,000	30.2
IW-3	9/29/03	-10	12,000	120.7
	10/14/03	5	2 (U)	<0.04
	11/13/03	35	2 (U)	<0.04
	12/16/03	68	2 (U)	<0.04
	2/18/04	132	2 (U)	<0.04
	9/21/04	348	2 (U)	<0.04
	4/21/05	560	2 (U)	<0.04
	10/20/05	742	2 (U)	<0.04
	3/28/06	901	46	0.46
	11/8/06	1126	27	0.27
	4/3/07	1272	87	0.88
IW-5	9/29/03	-10	5,600	56.3
	10/14/03	5	2 (U)	<0.04
	11/13/03	35	2 (U)	<0.04
	12/16/03	68	2 (U)	<0.04
	2/18/04	132	20	0.2
	9/21/04	348	420	4.2
	4/21/05	560	800	8.0
	10/20/05	742	2 (U)	<0.04
(Dup-1)	10/20/05	742	12	0.1
	3/28/06	901	50	0.5
(Dup-1)	3/28/06	901	2,600	26.2
	11/8/06	1126	1,100	11.1
	4/3/07	1272	2,000	20.1
IW-7	9/29/03	-10	4,300	43.3
	10/14/03	5	2 (U)	<0.04
	11/13/03	35	2 (U)	<0.04
	12/16/03	68	2 (U)	<0.04
	2/18/04	132	140	1.4
(Dup-1)	2/18/04	132	140	1.4
	9/21/04	348	800	8.0
	4/21/05	560	180	1.8
	10/20/05	742	59	0.6
	3/28/06	901	1,200	12.1
	11/10/06	1128	160	1.6
	4/3/07	1272	450	4.5
IW-10	9/29/03	-10	6,500	65.4
	10/14/03	5	2 (U)	<0.04
	11/13/03	35	2 (U)	<0.04
	12/16/03	68	2 (U)	<0.04
	2/19/04	133	2 (U)	<0.04
	9/21/04	348	NA	NA
	4/21/05	560	340	3.4
	10/20/05	742	2 (U)	<0.04
	3/28/06	901	210	2.1
	11/9/06	1127	240	2.4
	4/3/07	1272	1,100	11.1
Average of	9/29/03	-10	**9,680**	**97.4**
5 Injection Wells	10/14/03	5	**2 (U)**	**<0.04**
in Biobarrier	11/13/03	35	**2 (U)**	**<0.04**
	12/16/03	68	**89**	**0.9**
	2/18/04	132	**473**	**4.8**
	9/21/04	348	**1,356**	**13.6**
	4/21/05	560	**984**	**9.9**
	10/20/05	742	**190**	**1.9**
	3/28/06	901	**996**	**10.0**
	11/10/06	1128	**1,045**	**10.5**
	4/3/07	1272	**1,327**	**13.4**

DOWNGRADIENT MONITORING WELLS				
MW-6	9/30/03	-9	3,100	31.2
(7.5 feet)	10/14/03	5	2 (U)	<0.04
	11/13/03	35	2 (U)	<0.04
	12/16/03	68	18	0.2
	2/18/04	132	9.8	0.1
	9/22/04	349	200	2.0
	4/21/05	560	13	0.1
	10/20/05	742	5.1	0.1
	3/28/06	901	170	1.7
	11/10/06	1128	180	1.8
	4/3/07	1272	330	3.3
SMW-4	9/30/03	-9	7,400	74.4
(12.5 feet)	9/30/03	-9	7,400	74.4
	10/14/03	5	2 (U)	<0.04
(Dup-1)	10/14/03	5	2 (U)	<0.04
	11/13/03	35	2 (U)	<0.04
	12/16/03	68	2 (U)	<0.04
	2/18/04	132	2 (U)	<0.04
	9/22/04	349	2 (U)	<0.04
	4/21/05	560	2 (U)	<0.04
(Dup-1)	4/21/05	560	2 (U)	<0.04
	10/20/05	742	2 (U)	<0.04
	3/28/06	901	2 (U)	<0.04
	11/8/06	1126	20	0.2
	4/3/07	1272	2 (U)	<0.04
SMW-5	9/30/03	-9	13,000	130.8
(20 feet)	10/14/03	5	4,700	47.3
	11/13/03	35	2 (U)	<0.04
	12/16/03	68	170	1.7
	2/18/04	132	83	0.8
	9/22/04	349	450	4.5
	4/21/05	560	40	0.4
	10/20/05	742	4.1	0.04
	3/28/06	901	30	0.30
	11/9/06	1127	20(U)	<0.2
	4/3/07	1272	320	3.2
SMW-6	4/22/03	-170	7,000	70.4
(20 feet)	9/30/03	-9	5,800	58.4
	10/14/03	5	2,500	25.2
	11/13/03	35	21	0.2
	12/16/03	68	16	0.2
	2/18/04	132	7.5	0.1
	9/22/04	349	2(U)	<0.04
	4/21/05	560	2(U)	<0.04
	10/20/05	742	2(U)	<0.04
	3/28/06	901	2(U)	<0.04
	11/8/06	1126	240	2
	4/3/07	1272	13	0.13
SMW-7	9/30/03	-9	7,200	72.4
(20 feet)	10/14/03	5	6,500	65.4
	11/13/03	35	2 (U)	<0.04
	12/16/03	68	2 (U)	<0.04
	2/18/04	132	2 (U)	<0.04
	9/22/04	349	2 (U)	<0.04
	4/21/05	560	2 (U)	<0.04
	10/20/05	742	2 (U)	<0.04
	3/28/06	901	2 (U)	<0.04
	11/9/06	1127	50(U)	<.50
	4/3/07	1272	50(U)	<.50
Average of	9/30/03	-9	**8,667**	**87**
3 Monitor Wells	10/14/03	5	**4,567**	**46**
20 feet Downgradient	11/13/03	35	**8**	**0.1**
of Biobarrier	12/16/03	68	**63**	**0.6**
	2/18/04	132	**31**	**0.3**
	9/22/04	349	**151**	**1.5**
	4/21/05	560	**15**	**0.1**
	10/20/05	742	**2.7**	**0.03**
	3/28/06	901	**11**	**0.11**
	11/10/06	1128	**103**	**1.04**
	4/3/07	1272	**128**	**1.28**

a. "U" flag indicates concentration shown in table is 1/2 of Reportable Detection Limit (RDL);

i.e., the RDL is twice the concentration shown.
b. Where the analytical result is below the RDL, the "Average" concentrations were calculated using 1/2 of RDL as the concentration for that well at that event.

APPENDIX A, TABLE 3

Summary of Chlorinated Aliphatic Hydrocabons, Ethane, and Ethene in Groundwater (µg/L)

Well ID (Distance from barrier)	Sample Date	Days Since Injection 10/9/2003	1,1,1-TCA (µg/L)	1,1,1-TCA % reduction	1,1-DCA (µg/L)	1,2-DCA (µg/L)	Chloro-ethane (µg/L)	1,1-DCE (µg/L)	PCE (µg/L)	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	*trans*-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)	Total CAHs (µg/L)	Ethane (µg/L)	Ethene (µg/L)
UPGRADIENT MONITORING WELLS																
SMW-1	9/30/03	-9	17,000	-	40	<20	<20	1,200	110	160	<20	<20	<20	18,510	2.41	1.02
(25 feet)	10/14/03	5	13,000	-	270	<20	<20	1,000	52	170	<20	<20	<20	14,492	28.73	11.36
	11/13/03	35	9,300	-	110	<20	<20	910	22	330	26	<20	<20	10,698	1.53	0.30
	12/16/03	68	7,400	-	<20	<20	<20	730	<20	290	<20	<20	<20	8,420	0.40	0.15
	2/19/04	133	11,000	-	58	50	<20	820	50	320	<20	<20	<20	12,298	0.19	0.14
	9/21/04	348	7,900	-	83	<5	<5	840	20	260	23	<5	<5	9,126	0.14	0.12
	4/21/05	560	3,100	-	95	<5	<5	500	<5	220	18	<5	<5	3,933	0.20	0.21
	10/19/05	741	4,300	-	130	13	<5	830	11	300	26	<5	46	5,656	0.28	0.77
	3/27/06	900	700	-	23	17	<5	250	8	310	26	<5	26	1,360	0.05	0.24
	11/8/06	1126	5,300	-	63	<5	<5	580	7.1	290	28	<5	<5	6,268	0.09	0.16
	4/3/07	1272	3,700	-	71	<5	<5	420	<5	260	21	<5	24	4,496	0.18	0.37
SMW-2	9/30/03	-9	17,000	-	39	<20	<20	1,000	82	52	<20	<20	<20	18,173	4.28	1.94
(25 feet)	10/14/03	5	19,000	-	190	<20	<20	910	69	130	<20	<20	<20	20,299	4.60	1.68
	11/13/03	35	6,600	-	500	<20	<20	920	<20	73	<20	<20	<20	8,093	3.91	1.13
	12/16/03	68	8,500	-	<20	<20	<20	700	82	250	<20	<20	<20	9,532	0.79	0.20
	2/19/04	133	9,000	-	59	42	<20	690	58	200	<20	<20	<20	10,049	0.63	0.19
	7/20/04	285	7,900	-	41	<5	<5	670	39	200	12	<5	<5	8,862	0.54	0.27
	9/21/04	348	9,500	-	26	<5	<5	560	40	180	16	<5	<5	10,322	0.26	0.18
	4/21/05	560	4,200	-	61	<5	<5	400	<5	160	13	<5	<5	4,834	0.05	0.05
	10/19/05	741	6,600	-	80	15	<5	990	17	220	17	<5	9.9	7,949	0.11	0.13
	3/27/06	900	1,100	-	44	20	<5	370	7.0	280	23	<5	12	1,856	0.04	0.02
	11/9/06	1127	5,200	-	46	<5	<5	640	12	200	19	<5	<5	6,117	0.14	0.11
	4/3/07	1272	3,600	-	53	<5	<5	450	7.7	250	21	<5	<5	4,382	0.04	0.07
SMW-3	9/30/03	-9	14,000	-	<20	<20	<20	520	52	80	<20	<20	<20	14,652	1.50	0.54
(25 feet)	10/14/03	5	8,000	-	190	<20	<20	270	22	60	<20	<20	<20	8,542	0.51	0.21
	11/13/03	35	4,900	-	<20	<20	<20	260	30	64	<20	<20	<20	5,254	2.51	0.83
(Dup-1)	11/13/03	35	5,900	-	<20	<20	<20	300	30	82	<20	<20	<20	6,312	NA	NA
	12/16/03	68	11,000	-	<20	<20	<20	470	85	160	<20	<20	<20	11,715	0.22	0.10
	2/19/04	133	2,500	-	<20	75	<20	730	84	150	<20	<20	<20	3,539	0.04	0.04
	9/21/04	348	2,000	-	<5	<5	<5	88	7.7	23	<5	<5	<5	2,119	0.04	0.03
	4/21/05	560	6,800	-	26	<5	<5	420	13	210	17	<5	<5	7,486	0.10	0.11
	10/19/05	741	2,400	-	8.1	<5	<5	150	6.3	43	<5	<5	8.4	2,616	0.16	0.07
	3/27/06	900	1,700	-	41	<5	<5	260	5.0 J	240	20	<5	15	2,276	0.02	<0.01
	11/10/06	1128	3,200	-	33	<5	<5	210	8.0	78	9	<5	<5	3,538	0.01	0.02
	4/3/07	1272	3,800	-	170	<5	29	320	11	170	15	<5	<5	4,515	0.03	0.03

INJECTION WELLS																
IW-1	4/23/03	-169	17,000	-	65	<50	<50	610	90	170	<50	<50	<50	17,935	NA	NA
	9/29/03	-10	5,800	-	62	<5	<5	430	26	210	10	<5	<5	6,538	0.35	0.11
	10/14/03	5	580	90.0%	71	<5	<5	140	<5	16	9.1	<5	<5	817	1.17	0.41
	11/13/03	35	4,100	29.3%	130	<5	<5	310	16	250	26	<5	<5	4,832	0.16	0.19
	12/16/03	68	270	95.3%	1,400	<5	<5	160	<5	25	110	<5	<5	1,966	0.22	0.20
(Dup-1)	12/16/03	68	340	94.1%	1,600	<20	<20	150	<20	<20	130	<20	<20	2,221	NA	NA
	2/18/04	132	1,100	81.0%	1,200	18	340	160	<5	37	75	<5	<5	2,931	0.15	0.13
	9/21/04	348	3,900	32.8%	310	<5	380	460	11	110	85	<5	10	5,266	0.02	0.75
	4/21/05	560	470	91.9%	140	<5	140	110	<5	84	38	<5	<5	983	1.18	8.39
	10/20/05	742	250	95.7%	110	<5	200	41	<5	43	16	<5	17	678	11.13	7.33
	3/28/06	901	340	94.1%	55	<5	63	71	<5	120	63	<5	28	741	7.51	4.23
	11/9/06	1127	660	88.6%	100	<5	24	120	<5	110	64	<5	10	1,089	4.87	3.32
	4/3/07	1272	480	91.7%	32	<5	<5	96	<5	180	25	<5	13	827	1.77	0.73
IW-3	9/29/03	-10	9,300	-	50	<5	<5	560	42	150	5.5	<5	<5	10,108	0.94	0.34
	10/14/03	5	1,200	87.1%	140	<5	<5	180	<5	16	<5	<5	<5	1,537	1.94	0.73
	11/13/03	35	11,000	-18.3%	240	<5	<5	770	29	230	24	<5	<5	12,293	0.25	0.17
	12/16/03	68	160	98.3%	1,400	<5	<5	170	<5	<5	110	<5	<5	1,841	0.45	0.37
	2/18/04	132	1,800	80.6%	2,900	23	2200	370	10	11	130	<5	<5	7,445	0.13	0.12
	9/21/04	348	830	91.1%	1,500	<5	1000	540	6.3	17	200	<5	11	4,105	0.05	0.08
	4/21/05	560	940	89.9%	450	<5	600	180	<5	36	68	<5	73	2,348	0.05	15.08
	10/20/05	742	<5	99.7%	69	<5	770	<5	<5	<5	6.1	<5	37	883	12.85	22.67
	3/28/06	901	100	98.3%	130	<5	170	27	<5	23	46	<5	52	549	14.44	15.34
	11/8/06	1126	1,000	82.8%	370	<5	79	120	<5	78	52	<5	90	1,790	8.02	13.04
	4/3/07	1272	1,400	75.9%	120	<5	14	130	<5	150	28	<5	36	1,879	4.11	4.62
IW-5	9/29/03	-10	10,000	-	16	<5	<5	510	49	80	<5	<5	<5	10,655	0.34	0.12
	10/14/03	5	1,100	89.0%	70	<5	<5	220	<5	9.3	<5	<5	<5	1,400	2.09	0.69
	11/13/03	35	7,000	30.0%	15	<5	<5	460	23	92	8.6	<5	<5	7,599	0.25	0.12
	12/16/03	68	3,600	64.0%	290	<5	<5	190	36	78	8.7	<5	<5	4,203	1.50	0.41
	2/18/04	132	3,300	67.0%	1600	25	<5	180	24	48	43	<5	<5	5,221	0.13	0.10
	7/19/04	284	1,800	82.0%	750	<5	240	250	7.2	25	66	<5	<5	3,139	0.07	0.06
	9/21/04	348	2,300	77.0%	660	<5	980	320	8.2	40	110	<5	<5	4,419	0.05	0.03
	4/21/05	560	1,200	88.0%	230	<5	400	190	<5	57	45	<5	<5	2,123	0.04	3.09
	10/20/05	742	520	94.8%	340	<5	490	94	<5	32	40	<5	37	1,554	6.66	19.19
(Dup-1)	10/20/05	742	510	94.9%	360	<5	400	97	<5	32	41	<5	38	1,479	NA	NA
	3/28/06	901	330	96.7%	79	<5	81	77	<5	140	36	<5	24	768	2.77	4.88
(Dup-1)	3/28/06	901	330	96.7%	79	<5	76	77	<5	140	34	<5	22	759	NA	NA
	11/8/06	1126	2,000	80.0%	180	<5	72	160	<5	69	20	<5	17	2,519	4	3.9
	4/3/07	1272	2,300	77.0%	97	<5	23	210	<5	180	22	<5	22	2,855	1.5	1.49
IW-7	9/29/03	-10	6,000	-	16	<5	<5	280	26	28	<5	<5	<5	6,350	0.43	0.08
	10/14/03	5	1,200	80.0%	31	<5	<5	96	<5	8.5	<5	<5	<5	1,336	0.80	0.15
	11/13/03	35	3,900	35.0%	22	<5	<5	230	27	44	<5	<5	<5	4,223	0.19	0.12
	12/16/03	68	1,500	75.0%	<5	<5	<5	53	<5	14	<5	<5	<5	1,568	0.24	0.16
	2/18/04	132	4,000	33.3%	1400	24	<5	140	21	31	31	<5	<5	5,647	0.08	0.07
(Dup-1)	2/18/04	132	4,500	25.0%	1400	56	<20	170	35	32	36	<20	<20	6,229	NA	NA
	9/21/04	348	3,200	46.7%	740	<50	500	270	<50	<50	67	<50	<50	4,777	0.03	0.06
	4/21/05	560	890	85.2%	<50	<50	300	32 J	<50	<50	<50	<50	<50	1,191	0.10	2.85
	10/20/05	742	690	88.5%	350	<5	650	140	<5	26	32	<5	36	1,925	3.98	8.83
	3/28/06	901	180	97.0%	48	<5	87	40	<5	96	23	<5	20	495	5.60	5.14
	11/10/06	1128	1,500	75.0%	160	<5	120	110	<5	40	16	<5	17	1,964	2.40	2.14
(DUP-1)	4/3/07	1272	2,000	66.7%	110	<5	83	130	<5	130	20	<5	22	2,496	2.69	1.97
IW-10	9/29/03	-10	10,000	-	14	<5	<5	480	45	41	<5	<5	<5	10,580	0.18	0.08
	10/14/03	5	4,000	60.0%	42	<5	<5	300	<5	23	<5	<5	<5	4,366	1.79	0.24
	11/13/03	35	4,600	54.0%	260	<5	<5	250	51	67	<5	<5	<5	5,229	0.11	0.11
	12/16/03	68	1,500	85.0%	2,400	<5	<5	180	20	34	52	<5	<5	4,187	0.20	0.08
	2/19/04	133	5,300	47.0%	4,500	19	<5	400	29	40	110	<5	<5	10,398	0.04	0.05
	9/21/04	348	3,200	68.0%	1,400	<5	730	340	16	23	94	<5	<5	5,804	0.03	0.03
	4/21/05	560	3,500	65.0%	430	<5	550	480	<5	110	71	<5	<5	5,142	0.03	0.04
	10/20/05	742	200	98.0%	410	<5	730	88	<5	<5	35	<5	38	1,502	0.95	39.87
	3/28/06	901	290	97.1%	120	<5	240	53	<5	84	58	<5	38	884	15.56	22.80
	11/9/06	1127	2,500	75.0%	250	<5	110	170	<5	51	20	<5	17	3,119	5.78	6.13
	4/3/07	1272	3,600	64.0%	210	<5	<5	290	<5	210	29	<5	28	4,368	3.23	3.47

DOWNGRADIENT MONITORING WELLS																
MW-6	9/30/03	-9	5,700	-	6.6	<5	<5	270	25	36	<5	<5	<5	6,038	0.16	0.04
(7.5 feet)	10/14/03	5	5,300	7.0%	9.3	<5	<5	220	18	39	<5	<5	<5	5,586	0.15	0.03
	11/13/03	35	1,800	68.4%	7.1	<5	<5	150	6.3	25	<5	<5	<5	1,989	0.12	0.08
	12/16/03	68	270	95.3%	120	<5	<5	7.7	<5	<5	<5	<5	<5	399	0.10	0.03
	2/18/04	132	240	95.8%	1600	<5	1000	150	<5	<5	67	<5	<5	3,058	0.12	0.06
	9/22/04	349	960	83.2%	610	<50	1200	320	<50	<50	120	<50	<50	3,211	0.14	0.11
	4/21/05	560	1,000	82.5%	220	<50	530	59	<50	<50	<50	<50	<50	1,810	0.09	10.20
	10/20/05	742	300	94.7%	120	<5	680	27	<5	24	8.7	<5	18	1,179	23.75	2.58
	3/28/06	901	200	96.5%	98	<5	210	37	<5	71	11	<5	18	646	18.78	9.74
	11/10/06	1128	1,000	82.5%	200	<5	45	120	<5	51	23	<5	36	1,476	4.22	4.76
	4/4/07	1273	1,500	73.7%	100	<5	22	150	<5	150	25	<5	30	1,978	1.29	1.06
SMW-4	9/30/03	-9	14,000	-	27	<20	<20	720	66	73	<20	<20	<20	14,886	0.83	0.23
(12.5 feet)	9/30/03	-9	14,000	-	22	<20	<20	750	71	82	<20	<20	<20	14,925	NA	NA
	10/14/03	5	5,300	62.1%	24	<20	<20	270	21	60	<20	<20	<20	5,676	1.34	0.55
	10/14/03	5	5,200	62.9%	24	<20	<20	280	20	64	<20	<20	<20	5,589	NA	NA
	11/13/03	35	12,000	14.3%	45	<20	<20	730	46	140	<20	<20	<20	12,961	0.53	0.30
	12/16/03	68	760	94.6%	4,000	<20	<20	260	34	<20	140	<20	<20	5,195	0.12	0.09
	2/18/04	132	140	99.0%	2,800	<20	1600	320	<20	<20	140	<20	<20	5,001	0.13	0.07
	7/19/04	284	2,000	85.7%	580	<5	300	250	13	36	64	<5	<5	3,244	0.01	0.02
	9/22/04	349	3,700	73.6%	820	<5	380	260	16	38	70	<5	<5	5,285	0.06	0.07
	4/21/05	560	300	97.9%	400	<5	680	40	<5	13	21	<5	<5	1,455	0.11	23.99
(Dup-1)	4/21/05	560	310	97.8%	420	<5	700	37	<5	12	20	<5	<5	1,500	NA	NA
	10/20/05	742	1,000	92.9%	250	<5	420	120	<5	66	30	<5	50	1,937	30.31	8.12
	3/28/06	901	430	96.9%	86	<5	74	74	<5	200	31	<5	28	924	15.22	8.81
	11/8/06	1126	1,900	86.4%	320	<5	78	99	<5	47	30	<5	72	2,547	4.5	5.67
	4/3/07	1272	1,200	91.4%	120	<5	23	110	<5	140	29	<5	33	1,656	5.36	4.02
SMW-5	9/30/03	-9	14,000	-	46	<20	<20	790	65	150	<20	<20	<20	15,051	1.50	0.51
(20 feet)	10/14/03	5	10,000	28.6%	46	<20	<20	510	35	140	<20	<20	<20	10,731	0.35	0.12
	11/13/03	35	11,000	21.4%	92	<20	<20	1,000	34	240	<20	<20	<20	12,366	0.83	0.41
	12/16/03	68	760	94.6%	6,200	<20	<20	590	<20	<20	250	<20	<20	7,801	0.18	0.11
	2/18/04	132	340	97.6%	390	<20	8,700	620	<20	<20	200	<20	<20	10,251	0.22	0.09
	9/22/04	349	720	94.9%	1,400	<50	1,500	420	<50	<50	130	<50	370	4,541	0.19	0.16
	4/21/05	560	220	98.4%	270	<50	1,100	<50	<50	<50	<50	<50	<50	1,591	3.66	43.68
	10/20/05	742	300	97.9%	180	<5	580	10	<5	19	9.4	<5	44	1,143	26.38	20.12
	3/28/06	901	280	98.0%	130	<5	47	21	<5	98	19	<5	43	639	9.51	20.75
	11/9/06	1127	2,600	81.4%	430	<5	61	190	<5	160	46	<5	110	3,598	10.35	20.61
	4/3/07	1272	600	95.7%	120	<5	23	110	3.9[J]	150	32	<5	48	1,088	5.49	5.73
SMW-6	4/22/03	-170	25,000	-	<50	<50	<50	570	<50	82	<50	<50	<50	25,652	NA	NA
(20 feet)	9/30/03	-9	8,500	-	17	<5	<5	480	42	76	<5	<5	<5	9,115	0.21	0.05
	10/14/03	5	15,000	-76.5%	41	<5	<5	410	30	84	<5	<5	<5	15,564	0.40	0.11
	11/13/03	35	12,000	-41.2%	52	<20	<20	680	33	120	<20	<20	<20	12,885	0.60	0.48
	12/16/03	68	46	99.5%	26	<0.5	<0.5	3.7	<0.5	<0.5	1.1	<0.5	<0.5	78	0.08	0.03
	2/18/04	132	150	98.2%	1800	4.8	3200	210	12	7.6	110	<0.5	<0.5	5,495	0.12	0.09
	7/20/04	285	22	99.7%	95	<0.5	35	37	1.5	1.8	11	<0.5	<0.5	204	0.02	0.02
	9/22/04	349	650	92.4%	1400	<5	700	270	13	15	99	<5	<5	3,148	0.19	0.23
(Dup-1)	9/22/04	349	540	93.6%	930	<5	660	200	10	12	87	<5	<5	2,440	NA	NA
	4/21/05	560	440	94.8%	410	<5	900	5.1	<5	<5	<5	<5	<5	1,756	0.58	39.65
	10/20/05	742	290	96.6%	300	<5	550	5.2	<5	<5	<5	<5	27	1,173	24.10	28.19
	3/28/06	901	170	98.0%	150	<5	92	13	<5	40	13	<5	30	509	14.64	17.06
	11/8/06	1126	88	99.0%	10	<5	<5	5.6	<5	7.1	0.93	<5	<5	113	0.04	0.04
	4/3/07	1272	290	96.6%	77	<5	18	42	2	66	18	<5	32	546	1.33	1.45
SMW-7	9/30/03	-9	14,000	-	27	<20	<20	580	53	82	<20	<20	<20	14,742	1.16	0.49
(20 feet)	10/14/03	5	11,000	21.4%	400	<20	<20	520	26	60	<20	<20	<20	12,006	1.12	0.42
	11/13/03	35	8,900	36.4%	33	<20	<20	840	30	120	<20	<20	<20	9,923	0.71	0.32
	12/16/03	68	870	93.8%	6,300	<20	<20	380	<20	<20	160	<20	<20	7,711	0.98	0.23
	2/18/04	132	4,000	71.4%	4,300	63	1,900	380	54	41	120	<20	<20	10,859	0.15	0.09
	9/22/04	349	1,900	86.4%	1,100	<50	1,000	400	<50	<50	120	<50	<50	4,521	0.13	0.15
	4/21/05	560	900	93.6%	830	<50	1,100	94	<50	<50	<50	<50	<50	2,925	0.12	38.94
	10/20/05	742	49	99.7%	180	<5	1,000	11	<5	<5	<5	<5	16	1,257	24.41	44.99
	3/28/06	901	270	98.1%	170	<5	190	24	<5	57	17	<5	47	776	21.46	30.80
	11/9/06	1127	2,900	79.3%	260	<5	75	180	<5	79	34	<5	120	3,649	5.21	14.43
	4/3/07	1272	2,200	84.3%	290	<5	210	200	<5	130	43	<5	85	3,159	9.01	8.89

NA denotes not analyzed.

APPENDIX A, TABLE 4
Summary of Measured Groundwater Biogeochemical Parameters

Well ID (Distance rom Barrier	Sample Date	Days Since Injection 10/9/2003	Chloride (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Sulfate (mg/L)	Phosphate (mg/L)	Dissolved Iron (mg/L)	Arsenic (mg/L)	Manganese (mg/L)	Methane (µg/L)
UPGRADIENT MONITORING WELLS											
SMW-1	7/21/03	-80	17.6	16.2	<0.5	35.2	<0.5	NA	NA	NA	NA
(25 feet)	7/24/03	-77	16.6/16.7	15.5/15.6	<0.5/<0.5	32.6/32.3	<0.5/<0.5	NA	NA	NA	NA
	9/30/03	-9	17.6	11.0	<0.5	34.3	1.3	NA	NA	NA	0.4
	10/13/03	4	30.1	10.6	<0.5	42.0	1.8	NA	NA	NA	5.6
	11/13/03	35	18.8/18.8	10.4/10.4	<0.5/<0.5	32.1/31.8	1.6/1.8	NA	NA	NA	0.4
	12/16/03	68	21.9	10.9	<0.5	26.9	2.0	NA	NA	NA	1.0
	2/19/04	133	22.0	10.2	<0.5	31.7	2.5	NA	NA	NA	2.2
	7/20/04	285	19.1	8.2	<0.5	29.1	2.4	NA	NA	NA	NA
	7/23/04	288	18.7	7.1	<0.5	29.8	2.7	NA	NA	NA	NA
	9/21/04	348	20.7	6.5	<0.5	28.6	<10	NA	NA	NA	4.9
	4/21/05	560	21.8	7.0	<0.5	31.7	2.2	NA	NA	NA	7.1
	10/19/05	741	17.7	1.3	<0.5	28.4	<1	NA	NA	NA	6.4
	3/27/06	900	22.8	7.2	<0.5	28.4	2.4	NA	NA	NA	<0.2
	11/8/06	1126	21.0	14.6	<0.5	28	<10	NA	NA	NA	5.8
	4/3/07	1272	23.8/23.8	7.1/7.2	<0.5	29.1/29.2	NA	NA	NA	NA	7.5
SMW-2	7/21/03	-80	16.1	16.2	<0.5	34.2	<0.5	NA	NA	NA	NA
(25 feet)	7/24/03	-77	15.1	15.6	<0.5	31.2	<0.5	NA	NA	NA	NA
	8/26/03	-44	15.8/16.1	9.2/9.2	<0.5/<0.5	32.4/32.6	2.0/2.1	NA	NA	NA	NA
	9/30/03	-9	17.9	7.4	<0.5	34.4	1.8	<0.5	<0.010	0.36	0.6
	10/13/03	4	19.3	8.5	<0.5	33.6	3.9	1.9	<0.010	0.35	0.5
	11/13/03	35	20.0	9.8	<0.5	33.4	1.6	<0.5	<0.010	0.28	1.3
	12/16/03	68	16.2	6.7	<0.5	23.8	1.2	<0.5	<0.010	0.18	1.0
	2/19/04	133	17.8	10.0	<0.5	27.8	2.7	<0.5	<0.010	0.18	0.6
	7/20/04	285	16.9	6.0	<0.5	29.1	1.9	NA	NA	NA	3.7
	7/23/04	288	16.2	5.9	<0.5	28.3	3.1	NA	NA	NA	NA
	8/24/04	320	17.1	4.5	<0.5	28.3	<0.5	NA	NA	NA	NA
	9/21/04	348	18.9/19.2	6.0/6.1	<0.5/<0.5	25.9/25.3	<10/<10	<0.5	<0.010	0.13	3.6
	4/21/05	560	19.7	7.2	<0.5	26.6	2.4	<0.10	<0.010	0.17	1.7
	10/19/05	741	11.2	1.7	<0.5	16.6	1.5	<0.05	0.010	0.18	3.6
	3/27/06	900	22.1/21.7	10.2/10.2	<0.5/<0.5	27.3/27.2	2.3/2.3	<0.05	<0.010	0.16	<0.2
	11/9/06	1127	15.8	14.6	<0.5	20.3	<10	0.031[J]	<0.010	0.14	3.1
	4/3/07	1272	21	8.9	<0.5	25.0	NA	<0.05	<0.010	0.16	2.7
SMW-3	7/21/03	-80	14.2	6.9	<0.5	34.3	<0.5	NA	NA	NA	NA
(25 feet)	7/24/03	-77	14.4	4.6	<0.5	31.3	<0.5	NA	NA	NA	NA
	9/30/03	-9	14.1/14.8	7.0/7.2	<0.5/<0.5	26.4/26.5	2.0/2.2	NA	NA	NA	0.5
	10/13/03	4	16.2	4.2	<0.5	35.4	<0.5	NA	NA	NA	<0.2
	11/13/03	35	16.8/16.5	14.6/14.5	<0.5/<0.5	28.2/28.0	0.9/<0.5	NA	NA	NA	0.5
	12/16/03	68	18.3/17.8	11.0/11.0	<0.5/<0.5	24.3/24.2	1.7/1.8	NA	NA	NA	0.4
	2/19/04	133	17.0	15.2	<0.5	24.1	2.0	NA	NA	NA	<0.2
	7/20/04	285	13.5	8.7	<0.5	22.7	2.5	NA	NA	NA	NA
	7/23/04	288	13.8/13.6	8.7/8.7	<0.5/<0.5	23.4/23.4	2.6/1.9	NA	NA	NA	NA
	9/21/04	348	10.0	6.9	<0.5	18.8	<10	NA	NA	NA	0.9
	4/21/05	560	17.8	6.4	<0.5	24.0	1.7	NA	NA	NA	4.6
	10/19/05	741	7.5	12.0	<0.5	16.6	2.2	NA	NA	NA	18.2
	3/27/06	900	16.5	17.4	<0.5	23.3	<10	NA	NA	NA	<0.2
	11/10/06	1128	15.6	9.0	<0.5	17.0	<10	NA	NA	NA	0.8
	4/3/07	1272	20.4	6.3	<0.5	22.4	NA	NA	NA	NA	0.8

INJECTION WELLS											
IW-1	7/22/03	-79	17.2/16.7	16.4/16.7	<0.5/<0.5	28.4/28.2	<0.5/<0.5	NA	NA	NA	NA
	7/24/03	-77	12.0	12.2	<0.5	19.3	<0.5	NA	NA	NA	NA
	8/26/03	-44	18.9	14.7	<0.5	28.0	<0.5	NA	NA	NA	NA
	9/29/03	-10	18.0	13.9	<0.5	28.1	<0.5	NA	NA	NA	0.8
	10/13/03	4	19.0/18.6	<0.5/<0.5	<0.5/<0.5	23.2/23.0	<0.5/<0.5	NA	NA	NA	<0.2
	11/13/03	35	12.2/12.2	<0.5/<0.5	<0.5/<0.5	1.1/0.4	<0.5/<0.5	NA	NA	NA	8.3
	12/16/03	68	13.7/16	<0.5/<0.5	<0.5/<0.5	1.2/1.6	<0.5/<0.5	NA	NA	NA	166.0
	2/18/04	132	18.9	<0.5	<0.5	6.3	<0.5	NA	NA	NA	1,047
	7/20/04	285	14.6	<0.5	<0.5	6.9	<0.5	NA	NA	NA	NA
	7/23/04	288	16.4	<0.5	<0.5	10.2	<0.5	NA	NA	NA	NA
	8/24/04	320	15.6/15.7	<0.5/<0.5	<0.5/<0.5	11.0/11.2	<0.5/<0.5	NA	NA	NA	NA
	9/21/04	348	15.8	1.5	<0.5	12.0	<10	NA	NA	NA	3,637
	4/21/05	560	21.5	0.5	<0.5	15.7	<1	NA	NA	NA	3,437
	10/20/05	742	18.1	<0.5	<0.5	105.7	<1	NA	NA	NA	5,477
	3/28/06	901	25.8	2.3	<0.5	16.0	<10	NA	NA	NA	3,137
	11/9/06	1127	19.8	2.8	<0.5	22.8	<10	NA	NA	NA	4,257
	4/3/07	1272	33.7/27.9	3.7/3.2	<0.5	22.7/18.6	NA	NA	NA	NA	1,008
IW-2	7/22/03	-79	14.0	19.8	<0.5	28.6	<0.5	NA	NA	NA	NA
	7/24/03	-77	13.3/13.6	18.7/18.5	<0.5/<0.5	27.7/28.3	<0.5/<0.5	NA	NA	NA	NA
	8/26/03	-44	15.9	14.7	<0.5	29.6	<0.5	NA	NA	NA	NA
	7/20/04	285	14.7	<0.5	<0.5	<0.5	<0.5	NA	NA	NA	NA
	7/23/04	288	14.2	<0.5	<0.5		<0.5	NA	NA	NA	NA
	8/24/04	320	10.3	<0.5	<0.5	<0.5	<0.5	NA	NA	NA	NA
IW-3	7/22/03	-79	13.8	17.3	<0.5	30.9	<0.5	NA	NA	NA	NA
	7/24/03	-77	11.9	11.7	<0.5	21.6	<0.5	NA	NA	NA	NA
	8/26/03	-44	15.1/15.3	14.5/14.6	<0.5/<0.5	36.0/30.5	<0.5/<0.5	NA	NA	NA	NA
	9/29/03	-10	16.9	12.9	<0.5	30.1	<0.5	<0.5	<0.010	0.052	0.5
	10/13/03	4	13.1	<0.5	<0.5	27.6	<0.5	0.86	<0.010	3.6	0.5
	11/13/03	35	18.3	<0.5	<0.5	7.7	<0.5	69	0.011	16	2.7
	12/16/03	68	13.4	<0.5	<0.5	1.9	<0.5	24	<0.010	8.9	141.8
	2/18/04	132	23.0	<0.5	<0.5	1.4	<0.5	11	<0.010	4.1	395.4
	7/20/04	285	20.2	<0.5	<0.5	<0.5	<0.5	NA	NA	NA	NA
	7/23/04	288	18.6/18.6	<0.5/<0.5	<0.5/<0.5	1.4/1.5	<0.5/<0.5	NA	NA	NA	NA
	8/24/04	320	16.8	<0.5	<0.5	<0.5	<0.5	NA	NA	NA	NA
	9/21/04	348	23.8	<0.5	<0.5	2.7	<10	33	<0.010	3.1	2,043
	4/21/05	560	22.7	<0.5	<0.5	11.0	<1	30	0.0054 J	3.1	3,891
	10/20/05	742	25.5	<0.5	<0.5	<0.5	<1	52	0.021	3.3	7,330
	3/28/06	901	36.7	<0.5	<0.5	3.6	<10	18	0.0061 J	2.2	5,138
	11/8/06	1126	18.5	<0.5	<0.5	20.1	<10	15	<0.010	1.9	4,079
	4/3/07	1272	19.3	<0.5	<0.5	16.3	NA	7	<0.010	1.3	2,919
IW-4	7/22/03	-79	9.5	15.6	<0.5	25.7	<0.5	NA	NA	NA	NA
	7/24/03	-77	8.8	10.8	<0.5	14.9	<0.5	NA	NA	NA	NA
	8/26/03	-44	12.2	9.7	<0.5	26.5	<0.5	NA	NA	NA	NA
	7/20/04	285	10.9/11.0	<0.5/<0.5	<0.5/<0.5	2.2/2.3	<0.5/<0.5	NA	NA	NA	NA
	7/23/04	288	13.0	<0.5	<0.5	4.6	<0.5	NA	NA	NA	NA
	8/24/04	320	10.8	<0.5	<0.5	1.8	<0.5	NA	NA	NA	NA
IW-5	7/22/03	-79	10.8	14.5	<0.5	25.6	<0.5	NA	NA	NA	NA
	7/24/03	-77	10.6	13.8	<0.5	25.5	<0.5	NA	NA	NA	NA
	8/26/03	-44	14.0	11.3	<0.5	29.4	1.0	NA	NA	NA	NA
	9/29/03	-10	11.3	10.9	<0.5	23.9	2.7	NA	NA	NA	<0.2
	10/13/03	4	9.2	<0.5	<0.5	19.9	0.8	NA	NA	NA	0.9
	11/13/03	35	11.9	<0.5	<0.5	10.1	<0.5	NA	NA	NA	2.3
	12/16/03	68	9.0/10.0	<0.5/<0.5	<0.5/<0.5	2.0/2.3	<0.5/<0.5	NA	NA	NA	58.7
	2/18/04	132	13.1	<0.5	<0.5	2.7	<0.5	NA	NA	NA	136.0
	7/19/04	284	15.6/16.1	<0.5/<0.5	<0.5/<0.5	5.0/5.1	<0.5/<0.5	NA	NA	NA	2,251
	7/23/04	288	14.0	<0.5	<0.5	6.4	<0.5	NA	NA	NA	NA
	8/24/04	320	13.6	<0.5	<0.5	4.0	<0.5	NA	NA	NA	NA
	9/21/04	348	17.9/18.5	<0.5/<0.5	<0.5/<0.5	6.3/6.6	<10/<10	NA	NA	NA	5,394
	4/21/05	560	16.5	0.9	<0.5	16.3	<1	NA	NA	NA	2,919
	10/20/05	742	22.1	<0.5	<0.5	3.5	<1	NA	NA	NA	8,475
	3/28/06	901	22.8/22.8	0.5/0.6	<0.5/<0.5	20.1/20.4	<10/<10	NA	NA	NA	5,360
	11/8/06	1126	9.1	1.85	<0.5	19	<10	NA	NA	NA	3,002
	4/3/07	1272	20.7	3.2	<0.5	29.7	NA	NA	NA	NA	1,125

IW-6	7/22/03	-79	13.9/15.0	17.2/18.9	<0.5/<0.5	27.2/31.0	<0.5/<0.5	NA	NA	NA	NA
	7/24/03	-77	14.5	16.7	<0.5	30.3	<0.5	NA	NA	NA	NA
	8/26/03	-44	15.6	10.8	<0.5	31.1	1.9	NA	NA	NA	NA
	7/20/04	285	18.0	<0.5	<0.5	5.6	<0.5	NA	NA	NA	NA
	7/23/04	288	16.8	<0.5	<0.5	6.8	<0.5	NA	NA	NA	NA
	8/24/04	320	17.5/18.8	<0.5/<0.5	<0.5/<0.5	5.5/5.8	<0.5/<0.5	NA	NA	NA	NA
IW-7	7/22/03	-79	12.3	15.1	<0.5	28.8	<0.5	NA	NA	NA	NA
	7/24/03	-77	12.9/12.7	12.6/12.5	<0.5	30.1/29.5	<0.5	NA	NA	NA	NA
	9/29/03	-10	12.5/13.3	6.1/6.5	<0.5/<0.5	26.9/28.5	0.7/0.6	<0.5	<0.010	0.60	<0.2
	10/13/03	4	9.9	<0.5	<0.5	24.8	0.8	<0.5	<0.010	2.4	1.1
	11/13/03	35	11.0	<0.5	<0.5	11.9	<0.5	78	<0.010	13	24.9
	12/16/03	68	7.2	<0.5	<0.5	1.9	<0.5	26	<0.010	10	129.0
	2/18/04	132	13.3/13.7	<0.5/<0.5	<0.5/<0.5	4.4/4.4	<0.5/<0.5	29	<0.010	7.0	207.5
	7/20/04	285	10.9	<0.5	<0.5	4.3	<0.5	NA	NA	NA	NA
	7/23/04	288	14.3	<0.5	<0.5	8.5	<0.5	NA	NA	NA	NA
	9/21/04	348	18.0	<0.5	<0.5	12.0	<10	45	<0.010	5.0	4,638
	4/21/05	560	11.6/11.8	0.8/0.8	<0.5/<0.5	10.9/10.9	<1/<1	38	0.0081 J	5.4	3,879
	10/20/05	742	18.5	<0.5	<0.5	4.3	<1	54	0.014	5.9	5,375
	3/28/06	901	16.3	2.1	<0.5	15.5	<10	17	<0.010	2.9	4,935
	11/10/06	1128	9.7	2.2	<0.5	17.8	<10	12	<0.010	1.8	3,251
	4/3/07	1272	15.0	1.9	<0.5	23.8	NA	6	<0.010	1.8	3,930
IW-8	7/22/03	-79	13.4	14.8	<0.5	30.4	<0.5	NA	NA	NA	NA
	7/24/03	-77	12.1	11.9	<0.5	26.5	<0.5	NA	NA	NA	NA
	7/20/04	285	9.8	<0.5	<0.5	5.1	<0.5	NA	NA	NA	NA
	7/23/04	288	16.2/16.1	<0.5/<0.5	<0.5/<0.5	8.5/8.5	<0.5/<0.5	NA	NA	NA	NA
IW-9	7/22/03	-79	15.3	19.3	<0.5	28.9	<0.5	NA	NA	NA	NA
	7/24/03	-77	15.3	17.5	<0.5	29.3	<0.5	NA	NA	NA	NA
	7/20/04	285	16.8	<0.5	<0.5	1.6	<0.5	NA	NA	NA	NA
	7/23/04	288	20.9	<0.5	<0.5	5.2	<0.5	NA	NA	NA	NA
IW-10	7/22/03	-79	13.4	11.9	<0.5	27.1	<0.5	NA	NA	NA	NA
	7/24/03	-77	14.2	10.1	<0.5	31.3	<0.5	NA	NA	NA	NA
	9/29/03	-10	12.3	5.5	<0.5	27.5	1.7	NA	NA	NA	<0.2
	10/13/03	4	17.4	<0.5	<0.5	30.3	2.2	NA	NA	NA	0.3
	11/13/03	35	15.9	<0.5	<0.5	7.4	<0.5	NA	NA	NA	0.3
	12/16/03	68	17.3	<0.5	<0.5	2.6	<0.5	NA	NA	NA	0.8
	2/19/04	133	21.5	<0.5	<0.5	2.3	<0.5	NA	NA	NA	17.7
	7/20/04	285	16.9/16.9	<0.5/<0.5	<0.5/<0.5	4.9/4.8	<0.5/<0.5	NA	NA	NA	NA
	7/23/04	288	19.4	<0.5	<0.5	8.2	<0.5	NA	NA	NA	NA
	9/21/04	348	19.1	<0.5	<0.5	12.4	<10	NA	NA	NA	1,279
	4/21/05	560	20.9	0.5	<0.5	17.5	<1	NA	NA	NA	1,013
	10/20/05	742	27.9/28.3	<0.5/<0.5	<0.5/<0.5	<0.5/<0.5	<1/<1	NA	NA	NA	2,287
	3/28/06	901	23.1/23.2	<0.5/<0.5	<0.5/<0.5	12.2/12.2	<10/<10	NA	NA	NA	3,918
	11/9/06	1127	15.1	1.6	<0.5	17.1	<10	NA	NA	NA	4,438
	4/3/07	1272	19.9	3.1	<0.5	27.1	NA	NA	NA	NA	3,198

DOWNGRADIENT MONITORING WELLS											
MW-6	7/22/03	-79	8.5/8.8	11.9/12.0	<0.5/<0.5	22.9/22.7	<0.5/<0.5	NA	NA	NA	NA
(7.5 feet)	7/24/03	-77	11.5	15.1	<0.5	27.5	<0.5	NA	NA	NA	NA
	8/26/03	-44	12.9/13.0	10.3/10.2	<0.5/<0.5	28.4/28.6	0.9/0.8	NA	NA	NA	NA
	9/30/03	-9	6.6	4.6	<0.5	18.3	0.6	<0.5	<0.010	0.11	<0.2
	10/14/03	5	11.1/11.2	<0.5/<0.5	<0.5/<0.5	27.9/27.8	<0.5/<0.5	<0.5	<0.010	46	<0.2
	11/13/03	35	9.9	<0.5	<0.5	11.1	<0.5	1.8	<0.010	22	0.2
	12/16/03	68	1.5/1.8	<0.5/<0.5	<0.5/<0.5	9.4/12.7	<0.5/<0.5	1.3	<0.010	11	1.9
	2/18/04	132	2.5	<0.5	<0.5	12.6	<0.5	<0.5	<0.010	12	74.8
	7/20/04	285	3.3	<0.5	<0.5	13.1	<0.5	NA	NA	NA	NA
	7/23/04	288	11.0/11.3	<0.5/<0.5	<0.5/<0.5	10.5/10.5	<0.5/<0.5	NA	NA	NA	NA
	8/24/04	320	8.5	<0.5	<0.5	9.5	<0.5	NA	NA	NA	NA
	9/22/04	349	19.4	<0.5	<0.5	7.4	<10	37	<0.010	9.3	5,223
	4/21/05	560	17.2	<0.5	<0.5	8.7	<1	19	0.014	9.7	1,464
	10/20/05	742	28.9	<0.5	<0.5	3.6	<1	18	0.040	5.9	4,679
	3/28/06	901	31.2	<0.5	<0.5	11.9	<10	15	0.0075 J	5.8	4,352
	11/10/06	1128	11.0	2.9	<0.5	21.8	<10	5.5	<0.010	6.6	429.6
	4/4/07	1273	19.9	<0.5	<0.5	24..4	NA	6.8	<0.010	4	1,345
SMW-4	7/21/03	-80	11.8	16.6	<0.5	26.8	<0.5	NA	NA	NA	NA
(12.5 feet)	7/24/03	-77	12.0	16.1	<0.5	28.1	<0.5	NA	NA	NA	NA
	8/26/03	-44	14.4	10.7	<0.5	31.2	1.2	NA	NA	NA	NA
	9/30/03	-9	14.8/12.6	12.6/10.8	<0.5/<0.5	29.4/26.6	1.0/0.9	<0.5	<0.010	0.14	<0.2
	10/14/03	5	12.1/13.8	<0.5<0.5	<0.5/<0.5	42.4/43.8	1.1/0.6	1.2	<0.010	4.8	0.2
	11/13/03	35	15.9	<0.5	<0.5	8.0	<0.5	22.0	<0.010	14.0	0.6
	12/16/03	68	11.2	<0.5	<0.5	<0.5	<0.5	3.5	<0.010	19	0.5
	2/18/04	132	16.0/16.1	<0.5/<0.5	<0.5/<0.5	1.5/1.6	<0.5/<0.5	1.0	<0.010	15	75.7
	7/19/04	284	15.7	<0.5	<0.5	12.4	<0.5	NA	NA	NA	261.2
	7/23/04	288	15.7	<0.5	<0.5	11.4	<0.5	NA	NA	NA	NA
	8/24/04	320	14.7	<0.5	<0.5	10.2	<0.5	NA	NA	NA	NA
	9/22/04	349	16.8	<0.5	<0.5	12.6	<10	<0.5	<0.010	18	2,978
	4/21/05	560	17.4/17.2	<0.5/<0.5	<0.5/<0.5	8.2/8.2	<1/<1	23	0.0098 J	5.5	3,552
	10/20/05	742	19.8	<0.5	<0.5	5.1	<1	14	0.017	5.3	6,747
	3/28/06	901	25.0	<0.5	<0.5	15.3	<10	13	0.0064 J	3.0	3,434
	11/8/06	1126	11.7	<0.5	<0.5	21.9	<10	8.4	0.0077 J	2.2	1,142
	4/3/07	1272	21.4	<0.5	<0.5	28.6	NA	7	<0.010	2.4	2,573
SMW-5	7/21/03	-80	13.0	15.8	<0.5	25	<0.5	NA	NA	NA	NA
(20 feet)	7/24/03	-77	14.3	18.0	<0.5	31.4	<0.5	NA	NA	NA	NA
	8/26/03	-44	15.2	13.1	<0.5	31.1	<0.5	NA	NA	NA	NA
	9/30/03	-9	17.2	13.9	<0.5	31.6	<0.5	NA	NA	NA	0.4
	10/14/03	5	17.9/17.4	<0.5/<0.5	<0.5/<0.5	37.2/37.7	<0.5/<0.5	NA	NA	NA	<0.2
	11/13/03	35	25.4	<0.5	<0.5	5.2	<0.5	NA	NA	NA	0.6
	12/16/03	68	21.2	<0.5	<0.5	1.8	<0.5	NA	NA	NA	1.9
	2/18/04	132	23.4	<0.5	<0.5	2.2	<0.5	NA	NA	NA	497.9
	7/20/04	285	19.3	<0.5	<0.5	3.1	<0.5	NA	NA	NA	NA
	7/23/04	288	18.4	<0.5	<0.5	3.0	<0.5	NA	NA	NA	NA
	8/24/04	320	19.7	<0.5	<0.5	4.2	<0.5	NA	NA	NA	NA
	9/22/04	349	22.5	<0.5	<0.5	6.2	<10	NA	NA	NA	4,150
	4/21/05	560	24.8	<0.5	<0.5	0.9	<1	NA	NA	NA	3,117
	10/20/05	742	30.7/30.8	<0.5/<0.5	<0.5/<0.5	3.2/3.1	<1/<1	NA	NA	NA	6,634
	3/28/06	901	29.1	<0.5	<0.5	14.5	<10	NA	NA	NA	2,561
	11/9/06	1127	23.2	<0.5	<0.5	25.9	<10	NA	NA	NA	1,970
	4/3/07	1272	31.0	<0.5	<0.5	23.2	NA	NA	NA	NA	3,552
SMW-6	7/22/03	-79	13.4	17.4	<0.5	27.1	<0.5	NA	NA	NA	NA
(20 feet)	7/24/03	-77	13.0/13.2	18.3/17.9	<0.5/<0.5	28.4/28.5	<0.5/<0.5	NA	NA	NA	NA
	8/26/03	-44	14.8	11.3	<0.5	31.2	0.8	NA	NA	NA	NA
	9/30/03	-9	11.5	<0.5	<0.5	23.3	<0.5	<0.5	<0.010	0.11	0.3
	10/14/03	5	13.8	<0.5	<0.5	26.3	<0.5	<0.5	<0.010	1.3	<0.2
	11/13/03	35	13.8/14.2	<0.5	<0.5	5.6/5.7	<0.5	2.6	<0.010	1.4	0.5
	12/16/03	68	2.2	0.9	<0.5	12.7	<0.5	4.1	<0.010	2.4	<0.2
	2/18/04	132	14.6	<0.5	<0.5	6.8	<0.5	<0.5	<0.010	6.7	97.2
	7/20/04	285	3.1	<0.5	<0.5	8.4	<0.5	NA	NA	NA	500.4
	7/23/04	288	8.2	<0.5	<0.5	7.2	<0.5	NA	NA	NA	NA
	8/24/04	320	8.5/8.6	<0.5/<0.5	<0.5/<0.5	10.7/10.8	<0.5/<0.5	NA	NA	NA	NA
	9/22/04	349	15.7/17.7	0.8/<0.5	<0.5/<0.5	6.6/8.9	<10/<10	NA	<0.010	11	4,467
	4/21/05	560	15.4	<0.5	<0.5	6.5	<1	13	0.0049 J	3.6	2,194
	10/20/05	742	22.9	<0.5	<0.5	1.6	<1	14	0.017	6.8	5,797
	3/28/06	901	29.1	<0.5	<0.5	12.2	<10	13	<0.010	4.1	8,226
	11/8/06	1126	7.6	1.9	<0.5	11.0	<10	0.56	<0.010	0.037	8.7
	4/3/07	1272	12.5/14.7	1.6/1.6	<0.5	17.2/17.2	NA	5.9	<0.010	1.2	1,777
SMW-7	7/21/03	-80	14.9	17.8	<0.5	31.0	<0.5	NA	NA	NA	NA
(20 feet)	7/24/03	-77	12.3	14.4	<0.5	22.1	<0.5	NA	NA	NA	NA
	9/30/03	-9	14.3	8.4	<0.5	26.4	1.0	NA	NA	NA	<0.2
	10/14/03	5	25.2	4.1	<0.5	51.5	<0.5	NA	NA	NA	<0.2
	11/13/03	35	19.9	<0.5	<0.5	6.9	<0.5	NA	NA	NA	0.4
	12/16/03	68	13.6	<0.5	<0.5	9.8	<0.5	NA	NA	NA	0.5
	2/18/04	132	22.4	<0.5	<0.5	9.5	<0.5	NA	NA	NA	20.2
	7/20/04	285	19.7	<0.5	<0.5	2.9	<0.5	NA	NA	NA	NA
	7/23/04	288	18.4	<0.5	<0.5	3.4	<0.5	NA	NA	NA	NA
	9/22/04	349	21.0/20.6	<0.5/<0.5	<0.5/<0.5	8.5/8.5	<10/<10	NA	NA	NA	3,002
	4/21/05	560	20.8	<0.5	<0.5	8.2	<1	NA	NA	NA	3,359
	10/20/05	742	21.1	<0.5	<0.5	<0.5	<1	NA	NA	NA	4,826
	3/28/06	901	31.3/31.4	<0.5/<0.5	<0.5/<0.5	13.5/13.5	<10/<10	NA	NA	NA	5,187
	11/9/06	1127	19.0	<0.5	<0.5	24.9	<10	NA	NA	NA	1,657
	4/4/07	1273	21.0	<0.5	<0.5	24.5	NA	NA	NA	NA	5,426

NA denotes not analyzed.

APPENDIX A, TABLE 5
Summary of Field Measurements

Well ID (Distance from Barrier)	Sample Date	Days Since Injection 10/9/2003	Dissolved Oxygen (mg/L)	ORP (mV)	pH S.U.	Temperature (°C)	Conductivity (µS/cm)
UPGRADIENT MONITORING WELLS							
SMW-1	7/21/03	-80	NM	-97	6.04	21.5	346
(25 feet)	7/24/03	-77	NM	3	6.27	22.7	269
	9/30/03	-9	1.75	126	6.03	23.4	342
	10/13/03	4	0.83	97	5.95	22.0	395
	11/13/03	35	2.87	64	5.50	18.5	300
	12/16/03	68	1.91	103	5.80	14.3	300
	2/19/04	133	1.40	-199	5.80	9.0	286
	7/20/04	285	1.23	46	NM	22.1	200
	7/23/04	288	1.58	54	5.85	22.0	284
	9/21/04	348	1.00	113	5.84	23.7	286
	4/21/05	560	1.05	157	5.70	13.0	266
	10/19/05	741	0.85	136	5.62	23.1	343
	3/27/06	900	1.24	15	5.90	12.3	259
	11/8/06	1126	1.60	135	5.81	18.4	193.1
	4/3/07	1272	1.97	133	5.60	11.4	240
SMW-2	7/21/03	-80	NM	-19	5.82	19.7	291
(25 feet)	7/24/03	-77	NM	60	5.89	20.4	228
	8/26/03	-44	NM	204	6.50	21.8	310
	9/30/03	-9	1.56	147	5.89	21.7	248
	10/13/03	4	1.36	104	5.81	20.5	283
	11/13/03	35	1.71	66	6.40	17.6	260
	12/16/03	68	0.92	119	5.90	13.6	270
	2/19/04	133	2.71	-144	5.90	8.3	220
	7/20/04	285	1.49	-42	NM	20.8	190
	7/23/04	288	1.00	73	5.92	20	253
	9/21/04	348	0.92	117	5.91	21.8	252
	4/21/05	560	1.20	147	5.85	11.8	253
	10/19/05	741	1.18	146	5.79	21.1	291
	3/27/06	900	1.66	171	5.94	11.2	261
	11/9/06	1127	2.75	73	5.97	19.3	199
	4/3/07	1272	2.34	121	6.1	11	220
SMW-3	7/21/03	-80	NM	-53	5.99	20.3	244
(25 feet)	7/24/03	-77	NM	72	6.05	20.7	185
	9/30/03	-9	1.50	116	6.19	20.3	234
	10/13/03	4	0.68	84	6.07	19.9	253
	11/13/03	35	2.96	22	6.00	16.6	230
	12/16/03	68	1.46	79	6.20	12.1	190
	2/19/04	133	3.10	-351	6.00	7.7	193
	7/20/04	285	1.28	-17	NM	20.2	160
	7/23/04	288	1.16	75	6.00	20.4	239
	9/21/04	348	1.45	112	6.15	21.9	193
	4/21/05	560	1.38	142	5.97	11.2	230
	10/19/05	741	3.98	136	6.00	20.2	187
	3/27/06	900	4.70	177	6.06	10.2	237
	11/10/06	1128	2.60	58	6.50	16.6	131
	4/3/07	1272	2.41	100	6.9	10.8	220

INJECTION WELLS							
IW-1	7/22/03	-79	5.52	100	5.83	21.4	320
	7/24/03	-77	NM	80	5.96	20.8	268
	8/26/03	-44	NM	74	6.00	23.4	370
	9/29/03	-10	2.44	102	6.01	22.3	242
	10/13/03	4	0.86	45	5.93	21.4	422
	11/13/03	35	2.07	<-100	6.20	18.2	470
	12/16/03	68	1.33	-95	6.80	12.6	420
	2/18/04	132	0.98	-529	5.90	9.6	412
	7/20/04	285	0.97	-43	NM	20.4	390
	7/23/04	288	0.90	-16	6.40	20.2	444
	9/21/04	348	0.82	-59	6.34	22.2	390
	4/21/05	560	1.34	80	6.24	12.1	295
	10/20/05	742	0.93	-48	6.00	20.4	630
	3/28/06	901	1.43	-104	6.21	11.0	297
	11/9/06	1127	1.32	-33	6.09	20.3	332
	4/3/07	1272	2.24	-21	5.5	11.9	240
IW-2	7/22/03	-79	5.84	148	5.90	21.3	279
	7/24/03	-77	NM	123	5.99	20.8	231
	8/26/03	-44	NM	52	6.1	23.0	330
	9/29/03	-10	4.52	107	5.98	21.9	241
	10/13/03	4	1.32	78	5.74	21.2	958
	11/13/03	35	1.59	-99	6.3	18.0	460
	12/16/03	68	1.04	-88	6.5	13.5	310
	2/18/04	132	1.29	-139	6.1	10.2	502
	7/20/04	285	1.14	-62	NM	20.3	510
	7/23/04	288	0.91	-41	6.54	20.1	595
	9/21/04	348	0.74	-88	6.54	22.6	592
	4/21/05	560	1.10	51	6.56	13.0	405
	10/20/05	742	NA	NA	NA	NA	NA
	3/29/06	902	1.42	-101	6.61	12.0	347
	11/10/06	1128	1.18	-35	6.73	18.8	182
	4/4/07	1273	1.77	-72	7	9.4	370
IW-3	7/22/03	-79	7.50	131	5.94	20.7	286
	7/24/03	-77	NM	118	6.03	20.7	458
	8/26/03	-44	NM	55	6.1	22.7	320
	9/29/03	-10	2.23	106	6.10	22.3	248
	10/13/03	4	0.84	56	5.76	21.0	960
	11/13/03	35	1.44	<-100	6.8	18.2	430
	12/16/03	68	1.92	-125	6.5	14.8	440
	2/18/04	132	1.40	-160	5.9	10.0	379
	7/20/04	285	1.25	-56	NM	19.7	370
	7/23/04	288	0.77	-28	6.38	19.1	783
	9/21/04	348	1.07	-61	6.31	21.5	417
	4/21/05	560	1.49	34	6.30	11.9	349
	10/20/05	742	0.96	-87	6.27	19.7	574
	3/28/06	901	2.02	-126	6.43	11.5	343
	11/8/06	1126	1.30	-44	6.50	18.6	361
	4/3/07	1272	2.37	-64	6.00	12.3	270
IW-4	7/22/03	-79	6.02	164	5.79	21.0	186
	7/24/03	-77	NM	151	5.81	20.8	353
	8/26/03	-44	NM	110	6.2	22.3	260
	9/29/03	-10	2.42	131	5.87	22.0	197
	10/13/03	4	1.25	97	5.68	21.0	394
	11/13/03	35	1.73	-89	5.7	17.8	380
	12/16/03	68	1.02	-83	6.2	13.6	420
	2/18/04	132	1.43	-126	5.8	9.8	445
	7/20/04	285	0.91	-54	NM	20.1	500
	7/23/04	288	0.81	-19	6.3	19.7	713
	9/21/04	348	0.74	-71	6.41	22.1	506
	4/21/05	560	1.15	40	6.50	12.1	342
	10/20/05	742	NA	NA	NA	NA	NA
	3/29/06	902	1.43	-73	6.44	11.1	298
	11/10/06	1128	1.11	-12	6.65	17.7	159
	4/4/07	1273	2.62	-65	6.90	9.6	240
IW-5	7/22/03	-79	5.98	166	5.86	19.5	189.4
	7/24/03	-77	NM	134	5.92	19.8	190.6
	8/26/03	-44	NM	118	6.50	21.8	280
	9/29/03	-10	3.77	133	5.84	20.9	197
	10/13/03	4	0.91	71	5.72	21.0	379
	11/13/03	35	1.41	-82	6.10	17.8	280
	12/16/03	68	1.64	-106	6.10	13.4	290
	2/18/04	132	0.87	-410	7.00	8.9	282
	7/19/04	284	1.85	-85	6.20	20.1	310
	7/23/04	288	0.97	-31	6.54	19.2	343
	9/21/04	348	0.99	-55	6.47	21.7	402
	4/21/05	560	1.23	5	6.44	11.5	301
	10/20/05	742	2.73	-106	6.39	19.4	455
	3/28/06	901	1.84	-107	6.41	10.4	285
	11/8/06	1126	NM	-52	5.65	17.3	289

	4/3/07	1272	2.52	-6	6.30	12.6	230

IW-6	7/22/03	-79	6.30	165	5.74	19.0	259
	7/24/03	-77	NM	141	5.87	18.7	204
	8/26/03	-44	NM	136	6.8	20.9	300
	9/29/03	-10	4.48	129	5.95	20.3	215
	10/13/03	4	1.24	60	5.62	21.1	646
	11/13/03	35	1.09	-73	6.0	17.6	450
	12/16/03	68	1.22	-76	6.3	13.4	460
	2/18/04	132	1.32	-139	5.9	10.1	588
	7/20/04	285	0.95	-43	NM	19	340
	7/23/04	288	0.84	-30	6.44	18.2	416
	9/21/04	348	0.78	-48	6.18	22.0	435
	4/21/05	560	1.18	44	6.40	12.0	366
	10/20/05	742	NA	NA	NA	NA	NA
	3/29/06	902	1.11	-98	6.50	11.1	451
	11/8/06	1126		-47	5.85	17.4	392
	4/4/07	1273	2.21	-77	6.90	10.0	330
IW-7	7/22/03	-79	5.63	135	5.71	19.8	191.5
	7/24/03	-77	NM	127	5.81	19.8	185.3
	9/29/03	-10	3.46	137	5.98	20.7	180.2
	10/13/03	4	2.00	74	5.56	20.4	449
	11/13/03	35	1.42	-67	5.40	17.4	370
	12/16/03	68	2.08	-84	6.20	12.7	390
	2/18/04	132	0.98	-620	6.10	8.3	378
	7/20/04	285	1.13	-49	NM	19.7	390
	7/23/04	288	0.84	-35	6.41	18.9	410
	9/21/04	348	1.18	-42	6.26	21.0	388
	4/21/05	560	1.23	4	6.43	11.5	347
	10/20/05	742	0.99	-92	6.32	19.0	461
	3/28/06	901	1.31	-107	6.38	10.2	294
	11/10/06	1128	2.60	58	6.55	16.6	130.7
	4/3/07	1272	2.84	-26	6.5	13.0	230
IW-8	7/22/03	-79	5.90	132	5.69	19.9	233
	7/24/03	-77	NM	120	5.82	18.9	190
	9/29/03	-10	2.37	129	5.74	20.1	182.9
	10/13/03	4	1.03	81	5.68	20.5	615
	11/13/03	35	1.39	-70	5.6	17.1	410
	12/16/03	68	2.28	-88	6.5	13.2	430
	2/18/04	132	1.22	-743	6.6	8.7	328
	7/20/04	285	1.54	-39	NM	19	300
	7/23/04	288	0.89	-33	6.37	18.2	370
	9/21/04	348	0.91	-48	6.32	20.8	452
	4/21/05	560	1.31	32	6.55	12.1	317
	10/20/05	742	NA	NA	NA	NA	NA
	3/29/06	902	1.47	-100	6.62	10.7	303
	11/10/06	1128	2.08	42	6.61	18.1	162.8
	4/4/07	1273	2.25	-88	7	10.1	240
IW-9	7/22/03	-79	5.31	27	5.80	19.0	264
	7/24/03	-77	NM	85	5.95	18.0	211
	9/29/03	-10	1.89	129	5.89	19.7	201
	10/13/03	4	0.77	43	5.71	19.5	452
	11/13/03	35	1.87	-93	5.40	16.8	590
	12/16/03	68	2.64	-80	6.30	13.1	570
	2/18/04	132	1.45	-431	6.40	8.3	287
	7/20/04	285	1.48	-40	NM	18.4	240
	7/23/04	288	0.89	-34	6.35	17.8	318
	9/21/04	348	1.42	-40	6.24	20.0	293
	4/21/05	560	1.37	21	6.64	12.1	247
	10/20/05	742	NA	NA	NA	NA	NA
	3/29/06	902	1.24	-95	6.53	10.6	300
	11/10/06	1128	1.78	-24	6.73	16.8	159.1
	4/4/07	1273	2.97	-63	7	10.2	250
IW-10	7/22/03	-79	5.48	119	5.79	18.9	234
	7/24/03	-77	NM	118	5.90	17.8	186
	9/29/03	-10	1.76	126	5.79	19.9	198
	10/13/03	4	0.84	32	5.85	19.5	394
	11/13/03	35	1.98	-65	5.20	17.0	260
	12/16/03	68	1.50	-76	6.50	12.3	260
	2/19/04	133	1.26	-482	5.90	8.2	272
	7/20/04	285	0.75	-37	NM	18.2	250
	7/23/04	288	0.90	-37	6.45	18	330
	9/21/04	348	1.26	-29	6.33	20.1	307
	4/21/05	560	1.11	-4	6.31	11.0	273
	10/20/05	742	1.01	-71	6.31	18.2	466
	3/28/06	901	1.59	-120	6.35	11.1	270
	11/9/06	1127	1.62	-49	6.67	17.2	162.4
	4/3/07	1272	2.35	-12	6.8	11.1	230

DOWNGRADIENT MONITORING WELLS							
MW-6	7/22/03	-79	4.07	126	5.80	19.2	177
(7.5 feet)	7/24/03	-77	NM	149	5.85	18.8	193
	8/26/03	-44	NM	183	6.70	20.4	270
	9/30/03	-9	5.83	154	5.79	21.3	158
	10/14/03	5	0.85	109	6.32	20.8	297
	11/13/03	35	3.56	-50	5.90	17.5	300
	12/16/03	68	2.84	17	6.70	13.4	300
	2/18/04	132	2.96	-154	6.00	8.2	227
	7/20/04	285	0.88	-38	NM	20.4	140
	7/23/04	288	0.44	-22	6.58	18.9	388
	9/22/04	349	0.51	-62	6.57	21.3	397
	4/21/05	560	0.39	-53	6.59	11.8	310
	10/20/05	742	0.35	-98	6.52	19.5	464
	3/28/06	901	0.10	-60	6.49	11.0	332
	11/10/06	1128	3.21	57	6.35	19	151
	4/4/07	1273	0.03	20	6.50	10.1	230
SMW-4	7/21/03	-80	NM	75	5.75	18.6	235
(12.5 feet)	7/24/03	-77	NM	107	5.86	18.5	189
	8/26/03	-44	NM	152	6.30	20.9	280
	9/30/03	-9	1.54	154	5.64	20.7	225
	10/14/03	5	1.32	39	5.61	20.6	574
	11/13/03	35	1.49	<-100	5.80	17.8	390
	12/16/03	68	1.30	-90	6.60	14.0	370
	2/18/04	132	1.54	-49	6.30	9.0	317
	7/19/04	284	3.67	-46	7.37	19.0	280
	7/23/04	288	0.99	-28	6.88	18.4	386
	9/22/04	349	1.85	-60	6.80	20.5	387
	4/21/05	560	1.25	-21	6.80	11.3	374
	10/20/05	742	1.20	-149	6.77	19.9	82.0
	3/28/06	901	1.64	-105	6.82	10.5	365
	11/8/06	1126	1.99	20	5.50	17.1	194
	4/3/07	1272	2.77	-37	6.90	12.1	270
SMW-5	7/21/03	-80	NM	82	5.70	18.8	283
(20 feet)	7/24/03	-77	NM	99	5.89	18.0	221
	8/26/03	-44	NM	167	6.70	20.8	310
	9/30/03	-9	1.27	150	5.76	20.7	274
	10/14/03	5	0.69	60	5.85	20.5	439
	11/13/03	35	2.91	<-100	6.50	18.2	500
	12/16/03	68	1.79	-123	6.50	14.2	530
	2/18/04	132	3.90	-120	6.50	9.7	413
	7/20/04	285	0.64	-69	NM	17.8	380
	7/23/04	288	0.93	-46	6.89	17.9	533
	9/22/04	349	1.47	-86	6.83	20.4	489
	4/21/05	560	1.33	-53	6.84	11.8	417
	10/20/05	742	1.10	-146	6.73	19.2	481
	3/28/06	901	1.81	-120	6.90	10.6	394
	11/9/06	1127	1.57	-38	6.75	19.3	378
	4/3/07	1272	2.99	-77	7.1	11.1	330
SMW-6	4/22/03	-170	NM	NM	6.05	8.8	245
(20 feet)	7/22/03	-79	NM	80	5.76	19.4	235
	7/24/03	-77	NM	98	5.93	17.6	190
	8/26/03	-44	NM	165	6.90	20.4	290
	9/30/03	-9	4.66	154	5.39	20.4	145
	10/14/03	5	1.67	107	5.61	19.4	258
	11/13/03	35	2.94	-89	6.40	17.6	430
	12/16/03	68	3.11	12	6.20	14.0	450
	2/18/04	132	2.69	-154	6.10	10.1	199
	7/20/04	285	2.94	-59	5.66	18.8	80
	7/23/04	288	2.29	-12	5.97	18.5	176
	9/22/04	349	1.53	-71	6.66	20.0	404
	4/21/05	560	1.69	-8	6.45	12.1	233
	10/20/05	742	1.30	-130	6.70	18.9	429
	3/28/06	901	2.45	-50	6.54	10.6	299
	11/8/06	1126	3.67	121	5.46	16.4	86.4
	4/3/07	1272	4.76	67	7.70	11.9	150
SMW-7	7/21/03	-80	NM	17	5.79	18.4	264
(20 feet)	7/24/03	-77	NM	85	5.90	17.1	203
	9/30/03	-9	1.72	146	5.79	19.2	228
	10/14/03	5	1.36	115	5.70	18.9	254
	11/13/03	35	1.09	<-100	6.30	17.1	440
	12/16/03	68	0.94	-86	6.70	13.0	210
	2/18/04	132	1.41	116	6.20	9.6	320
	7/20/04	285	1.09	-100	NM	17.1	350
	7/23/04	288	1.51	-33	6.85	17.6	490
	9/22/04	349	1.17	-73	6.87	20.1	453
	4/21/05	560	1.49	-22	6.81	11.6	383
	10/20/05	742	1.18	-148	6.79	18.3	70.8
	3/28/06	901	1.90	-156	7.06	10.7	435
	11/9/06	1127	1.80	-55	6.87	18.1	365

	4/4/07	1273	2.31	-145	7.1	10.2	360

NM denotes not measured.

ORP measurements rounded to nearest whole number.